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OPENCAST PROSPECTS IN THE HUNTLY AND WAITEWHENA COALFIELDS

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[*Received for publication, 20th June, 1945*]

Summary

The paper contains a brief account of areas in the Huntly and Waitewhena coalfields suitable for opencast mining by bulldozer and carry-all equipment. Some of the areas described are now exhausted and others are being developed.

Opencast mining is fundamentally a problem of earth shifting and disposal, and up to the present time the scope of stripping operations in New Zealand has been determined by the available mechanical equipment; a wider application of opencast methods would involve much heavier and more costly machinery than is now available in this country and would also necessitate quantity surveys over wider areas, in conjunction with extensive boring programmes. This major aspect of opencasting is a long-term project and offers no immediate relief for the coal shortage in the North Island, but may follow as a result of the present experience in opencasting throughout New Zealand.

INTRODUCTION

To supplement the coal-supplies from established mines in the North Island, areas likely to contain strippable coal were investigated in the Huntly and Waitewhena coalfields. Though little is known of the probable northward extension of the Huntly field, a considerable amount of information is available regarding its southern or outcrop portion, in which all the mines of the Waikato are now operating or have been situated in the past. Naturally, the best or most obvious areas of workable coal handy to access are first worked in any coalfield, and Huntly is no exception; but the stage has now been reached when the outcrop portion of this field is, with the exception of parts held by the Taupiri Coal-mines, Ltd., fully developed and pillars are extracted over much of the workable area. Outcrops in this coalfield are not abundant, and the coal oxidizes and weathers deeply to an end product that is indistinguishable from the associated strata. Apart from one area at Glen Afton, isolated from the main workings of Pukemiro Collieries, but known, from borehole information, to contain 70,000 tons of coal, additional areas had of necessity to be sought adjacent to, or as possible extensions of, known workings where depth of overburden was not excessive. There are two areas handy to Huntly containing strippable coal; these are the Waikato Extended area, from which the first coal of the Waikato was won from the Kupakupa Mine, and the Taupiri East area.

HUNTLY COALFIELD

Taupiri East Area.—The Taupiri East area of coal-measures is at the south end of Lake Kimihia, from under which 337,000 tons of coal were won up to 1910 in developing the Taupiri Reserve Mine. This mine is now closed and the workings are flooded. Since 1910 about 50,000 tons have been won from the upper part of the mine and the adjacent lake-shore. Two other small areas were worked at the south end of this patch, on one of which is the Kimihia No. 4 opencast workings.

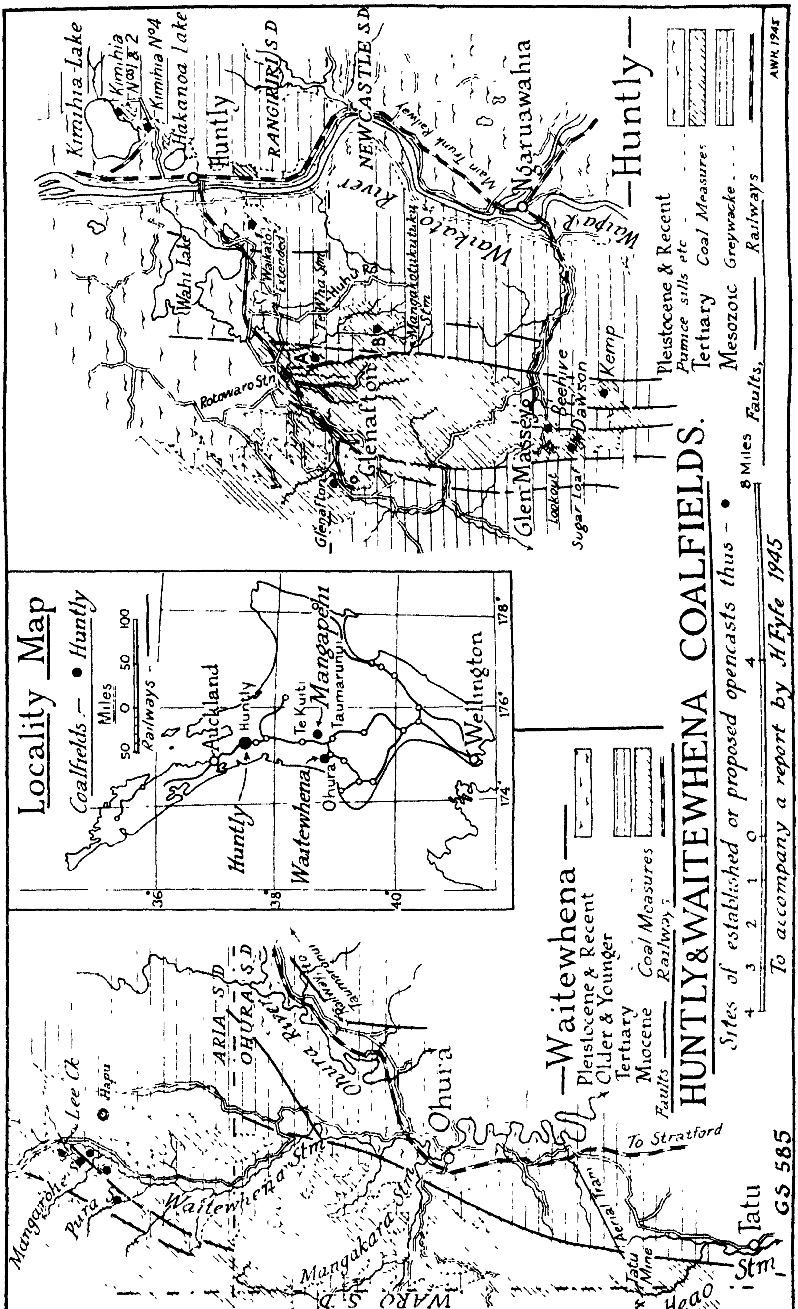
A major scheme for the recovery of coal standing in pillars at the Taupiri Reserve Mine was proposed by Mr. R. Schoen, of the Mines Department, entailing the pumping of the lake and thereby removing any danger of flooding the mine when the country caved with pillar-extraction. The proposal was investigated by the Public Works Department, and though economically sound, the scheme offered no immediate relief from the acute coal shortage then facing the country; further, there was an element of risk, as the ground between the lake and the Waikato consists of pumice silt, and in the event of considerable seepage from the river back into the lake basin the scheme might prove unworkable. A considerably modified scheme was subsequently undertaken by Downer and Co., Ltd., to recover some of the shallower coal under the south end of the lake; this involved cutting off part of the lake with a stop-bank and the subsequent stripping of the enclosed area and recovery of the coal by a drag-line. This project is now well under way, and an area of 21 acres has been enclosed by an earth-work coffer-dam 30 ft. wide at the top and battered at about ½ to 1. Some 71,000 yards of spoil was used in the construction of this stop-bank, which was so consolidated by the tractors and carry-alls used in its construction as to be completely water-tight. It is expected that 100,000 tons of coal will be won from this No. 1 Opencast.

Mr. R. T. H. Dale, Inspector of Coal-mines, has suggested that much of the shallow coal around Huntly that can never be won by orthodox mining methods because of the danger of the thin mudstone roof collapsing and allowing the overlying water-logged pumice silts to flood the workings, as has happened in the past in the abandoned Taupiri Extended Mine,* could be recovered by dredging.

It was known from drill records that during the Pleistocene the coal had been eroded from an area between lakes Hakanoa and Kimihia; and the seam at the top of the dip in the Taupiri East Mine is cut off by an old erosion surface and overlain by decomposed pumice of Pleistocene age that filled ancient valleys during a period of depression; this decomposed pumice crops out at places along the lake-shore west of the mine and forms much of the hill country between the two lakes. Later than this period of erosion there was at least another and probably several periods when some part of the seam was being eroded by the streams during down-cutting following elevation of the land; the seam at the fan "shaft" of the Taupiri Reserve Mine is overlain by only a foot of fireclay, followed by pumice silts of late Pleistocene or Recent age. Other parts of the seam were probably eroded at this period as well as at succeeding periods of part-base-levelling†. Faulting of a minor order, but sufficient to introduce difficulties in stripping, are almost impossible to recognize on account of the deep mantle of weathered rock and the paucity of outcrops. To obtain some idea of the

* *Mines Statement, 1888; C.-4*, p. 2; *ibid.*, 1916, *C.-2*, p. 64.

† For an account of the physiographic development of the lower Waikato basin, see J. Henderson and L. I. Grange, *Bull. No. 28, N.Z.G.S.*, "The Geology of the Huntly-Kawhia Subdivision," 1926, pp. 26–29.


HUNTLY & WAITEWHENA COALFIELDS.
Sites of established or proposed opencasts thus - ●
To accompany a report by H Fyfe 1945
GS 585
AWH 1945
—Huntly—
Pleistocene & Recent
Pumice sills etc
Tertiary Coal Measures
Mesozoic Greywacke
Faults, Railways
—Waitewhena—
Pleistocene & Recent
Older & Younger
Tertiary
Miocene Coal Measures
Faults Railways
Locality Map
Coalfields - ● Huntly
Miles
Railways
Auckland
Huntly
Waitewhena
Te Kuiti
Taumarunui
Mangapehi
Ohura
Wellington
Kimihia Lake
Hakanoa Lake
Huntly
RANGIRIRI S D
NEWCASTLE S D
Waikato River
Ngaruawahia
Waipa R
Main Trunk Railway
Wahi Lake
Rotowaro Stn
Glenafton
Glen Massey
Beehive
Dawson
Kemp
Lookout
Sugar Loaf
Te Wha Stm
Ohura
Waitewhena Stm
Mangakara Stm
Mangaroho
Pura
Lee Ck
Hapu
ARIA S D
OHURA S D
WARO S D
To Stratford
Aerial Tram
Tatu Mine
Tatu
Stm
Heao

probable extent of coal-bearing ground, the Air Mapping Branch of Lands and Survey Department kindly prepared a 50-ft.-interval contour map of the area south of Lake Kimihia, using the lake-shore as datum; the intersection of these contours with corresponding structure contour of the coal-seam, prepared on the assumption that the strike of the coal did not differ markedly from that of the seam of the Taupiri Reserve Mine and that the dip was constant from the lake-shore to two outcrops at the south end of the area, permitted the blind outcrop of the seam to be drawn and suitable localities for drill-holes to be chosen. The drill-log showed that over much of the area, erosion and faulting of the seam prohibit the development of any extensive stripping area, but proved two small patches of strippable coal; one, the Kimihia No. 4 Opencast, estimated to contain 40,000 tons, had produced 30,800 tons up to December, 1944; the other, known as No. 2 Opencast, is now in production and contains from 10,000 tons to 15,000 tons of coal. It is in a small spur some 10 chains south of No. 1.

A feature partly revealed by the bores and further disclosed by the stripping is the extent to which the coal weathers to a brownish-black powder on the roof, and in from the outcrop, where subjected to percolating water; one drill-hole showed 10 ft. of hard coal on the floor overlain by 10 ft. of powdery coal; and at the south-west corner of the area, where the whole seam, under about 20 ft. of cover is a chain across, the coal is completely powdered.

Waikato Extended. Both the East Taupiri and Waikato Extended areas show patches of clay boulders baked by the burning of the seam in some prehistoric fire. What thickness of the seam was consumed by these fires is unknown, but in no case has it been established that the entire thickness of it was involved. This baked clay shows at the bins of the Waikato Extended Mine, and blocks of it can be traced on the hillside in places where the seam is at little depth below the surface, almost as far south as the abandoned workings on the hilltop. The seam dips north-westwards more or less in conformity with the gentler slopes adjacent to the mine, and northwards, apart from minor faults and some erosion of the coal, the seam is continuous with that of the old Taupiri West workings. West of the Waikato Colliery's abandoned working, which, so far as can be judged from the unoriented plan of that mine, occupied about 23 acres immediately west of the present Waikato Extended Mine, is an area approximately of 5 acres that may contain strippable coal. A small cut at the south of this area shows 6 ft. of clean coal, and in the neighbouring Waikato Extended Mine the seam is more than 10 ft. thick.

Some boring and prospecting has recently been carried out by the Roose Shipping Co. on the flat area between the present Waikato Extended Mine and Mr. Fisher's residence, and it is understood that a 30 ft. seam has been proved thinning out to the east and north. Details of this area are not available as yet, but there are indications that the Roose Shipping Co. is making arrangements to work this area in the near future.

Rotowaro. -There are two areas, handy to Rotowaro, held by the Taupiri Mines, Ltd., that are worth investigating as stripping propositions. They are denoted on the map as A and B. The former is contained between two meridional faults, and it extends south to the greywacke-coal-measure contact. The coal-measures apparently dip to the north, but at the 6 ft. outcrop, close by a power-line pole some 38 chains due south of the road bridge over Awaroa Stream, are practically flat-lying. Locally this is known as Crooks's outcrop. Southward from this the coal-measures apparently rise gently.

Much of this area is of low relief, and is surrounded on the north, east, and west by swampy ground, so that disposal of spoil may prohibit extensive stripping; about 30 chains or 40 chains of roading would also be required. There may, however, be sufficient coal to warrant stripping, but until one or two bores are put down it is a problematical stripping proposition.

Area B comprises about 130 acres and is apparently part of a more extensive area of coal-measures. Three outcrops of coal are known, one showing 6 ft.+ of clean coal in a small branch of a tributary of Te Wha Stream, the other showing 7 ft.+ of coal which forms a small waterfall in the main tributary. This latter outcrop shows "blobs" of iron-stained dirty coal about 3 ft. in diameter which apparently represent crushed patches discoloured by percolating solutions: the surrounding coal is clean, bright, and hard. It is just possible that a minor fault determines the meridional course of this tributary and that the coal underlying it is similarly dirty; but it is not anticipated that these dirty patches are extensive. The third outcrop shows dirty, unworkable coal.

The contours show that there is ample room for disposal of overburden in the Mangakotukutuku valley, but the lead would be excessive for disposal of all the spoil there; in the tributary of Te Wha Stream, facilities for spoil disposal are not so good.

Data are too scant to give any estimate of the strippable coal either of these areas may contain, and prospecting is essential before any work is done. If it be assumed that area B contains an average of 6 ft. of coal over 130 acres, it contains over 1,000,000 tons.

Glen Afton Opencast. This is an area of 7 acres adjacent to abandoned Glen Afton workings that had previously been drilled by the Pukemiro Collieries, but is isolated from the workings of that company by a patch of thin coal. The ratio of overburden to coal is 5 to 1 over the strippable area, which is handy to the railway, being within a few chains of the Glen Afton backshunt, an extension of which was taken to the opencast. The overburden, consisting of mudstone and fireclay, requires little shooting and is removed by D.H. 8 Diesel-driven tractors and carry-alls of 12 cubic yards capacity, the average lead being 11 chains to a hillside waste-dump.

When work began at this opencast the coal was lifted straight from the face into the wagon, the shovel being large enough to do this without shooting the coal. In this way a very good sample of run-of-mine coal was produced. At other opencast mines, where generally an R.B. 10, ⅜ yard, shovel is used, it is found that without some shooting the wear-and-tear on the shovel becomes excessive and repairs frequent and costly.

As the face advanced from the railway-line and to provide urgently needed slack for industry, a simple type of bar screen to make small coal and domestic coal was built; the coal was rooted from the face with an angle dozer and further broken by pushing the coal so won to the screen, where it was elevated with the shovel and the separated classes of coal allowed to run into the wagons.

Up to the time that the mine closed for the winter in May of 1944, 10,600 tons had been produced.

On reopening in December last, the loading system was reorganized by shifting the screen to an elevated point near the township end of the mine, by removing the railway-line which was dipping into the mine property, and by constructing a properly graded loop at the screen. The coal is

loaded from the face without shooting by the R.B. 20 shovel into 2 yard Dodge dump cars, which are well suited to this class of work, and tipped on to a chute from which the coal is screened. The writer has not seen better-screened coal than that prepared by this simple arrangement, though the screening was affected to some extent in the wet weather. A total of 2,600 tons was railed during the latter part of December, and given average weather during the remainder of the year, good results should be had from this mine.

Dawson's Lookout, Glen Massey. This area of roughly 240 acres of coal-measures is about two miles west from Glen Massey Railway-station on the south side of the only road leading in that direction. The geological map of Newcastle Survey District shows the coal-measures bounded by two meridional faults capping the ridge between the headwaters of Ohautira and Paiakahauhau streams. Two prominences surmount this otherwise fairly even-topped ridge; the one by the road is known as the Lookout, the other, a mile south, as the Sugarloaf. About 60 chains south of this are the workings of Wilton Collieries No. 2 Mine. Four outcrops of coal are recorded on the map, the most northerly of which shows 6 ft. of coal, but this outcrop was not relocated. Forty chains east of it the seam is only 1 ft. thick, and outcrops along this eastern side of the ridge show only stony or thin coal coinciding with a barren patch extending through the Wilton Collieries area. Thirty chains south-west of the Sugarloaf are two outcrops showing 5 ft. 6 in. of coal. Throughout the area the coal-measures, consisting of mudstones with a resistant glauconitic sandstone band about 35 ft. above the coal-seam, dip gently westwards, and the topography is ideal for ready disposal of spoil. Apart from the necessity of proving the amount of overburden, the area required boring to show the extent of workable coal. A ready method for estimating the amount of overburden was afforded by aerial photos. The glauconitic sandstone, which shows up clearly on the photos, was assumed as horizontally bedded, and using the base of this stratum as datum the Aerial Mapping Branch of the Lands and Survey Department kindly ran form lines at 50 ft. intervals; a rough estimate gave the average thickness of overburden between the two high points on the ridge as 90 ft. A drill-hole 24 chains S. 33° W. from the Lookout proved 100 ft. of overburden on 6 ft. of coal; another hole 44½ chains S. 27° W. from the Lookout proved 80 ft. of overburden on split, dirty coal. These two holes are sufficient to show that the overburden over most of the area, if not over the whole, is excessive for stripping, though some coal will ultimately be won from it by normal mining methods from the present Wilton workings.

Kemp's Area.—An area of 57 acres one mile and a half south of Glen Massey, in which the coal-measures dip gently to the south-west, has been proved by twelve bores. Three coal-seams are present, of an average thickness of 1 ft. 8 in., 4 ft., and 6 ft.+ from top to bottom. The maximum thickness of overburden above the top seam encountered in prospecting is 30 ft.; the mudstone between the top and middle seams averages 10 ft., and between the middle and bottom seams 12 ft. Estimates taken out by Mr. T. L. Browne give a ratio of 6·2 yards of spoil per ton of coal for the recovery of 480,000 tons of coal. Overburden amounting to 414,000 cubic yards has now been removed from a section of the top seam and a smaller section of the mid seam, and a start has been made to prepare the bottom seam for working along its outcrop.

In late December, 3,000 tons were produced from the two top seams near their outcrops, where the seam is thinner than usual and somewhat friable. Consequently, an excessive amount of small coal was produced,

though the screened product was of excellent quality and well prepared for the market. All the slack so made was readily accepted by consumers.

In general, it may be stated that the screening of opencast coal improves the product from the consumer's point of view, and in future no opencast areas should be worked without provisions being made for such processing.

Beehive Area.—This small area south of Dawson's Road, Glen Massey, was previously worked by Waipa Collieries, and to ease the coal position a strip about 1 chain wide by 10 chains long was worked. The Waipa Collieries had formed their pillars right up to the outcrop, and these pillars had been split and robbed, leaving the minimum amount of coal necessary for safe underground mining; but it was still possible to recover safely this abandoned coal by "taking the top off" Unfortunately, the sidelong country is rising so steeply that it was not possible to recover more than 4,000 tons of coal without the overburden becoming excessive.

WAITEWHENA COALFIELD

The centre of the Waitewhena Coalfield is 12½ miles up Waitewhena Stream from Ohura Township, and access is provided by a narrow metalled road leading to Aria. This road is the bottle-neck for production from the field, which will not become an important coal-producer till railway access is provided. The geology of the coalfield is well known and is described by Grange, who incorporated the earlier work of Ongley in the bulletin on "The Tongaporutu-Ohura Subdivision." There are no underground workings. A few areas fairly handy to the road are worth investigating as stripping propositions, chiefly to determine the amount of overburden, for coal outcrops are numerous, the structure, apart from the major faults already mapped, is not complicated by folds and faults, and the seam maintains its height and freedom from dirt or stone bands, so that the coal at the outcrop is a reliable indication of what the seam will be like 5 chains or 10 chains under cover.

Lee Creek. Lee Creek is a small stream joining the Waitewhena from the west 70 chains north-west from Hapu Trig. The seam, in bushed country, is at least 12 ft. thick here and may, as suggested by Ongley's observations, be as much as 25 ft. thick, provided it is not repeated by minor faulting. The outcrop is within 20 chains of the road and the area is now being developed as a stripping area from which production can early be expected.

Mangarohe Stream.—Four outcrops around the spur end on the north side of Mangarohe Stream show a height of coal ranging from 6 ft. to 12 ft.; at two of the outcrops the coal is 10 ft. thick. The area is on the east side of the Waitewhena Fault and covers about 1½ acres. If an average height of coal of 9 ft. is assumed for the seam throughout, there is about 20,000 tons of coal in the ground.

There is a knob on the south side of Mangarohe Stream, 30 chains south-west from Lee Creek and also east of the Waitewhena Fault. Well-spaced outcrops around this knob show that it is underlain by a coal-seam at least 8 ft. and possibly as much as 20 ft thick. The overburden does not appear excessive for stripping, but becomes heavy about the centre of the patch.

At the same locality, but west of the fault and downthrown roughly 100 ft., the seam may prove to be as much as 19½ ft. thick; there appears to be at least 4 acres of strippable coal in these two latter areas.

On the north side of the Mangarohe valley the coal for 2 chains or 3 chains back from the outcrop and for roughly 5 chains along it has only

a shallow cover, just a few feet at the outcrop, but making to greater thickness to the back; the seam here is at least 10 ft. or 12 ft. thick. This area is bushed, about half a mile from the road, and roughly 200 ft. above the main stream. A mile or so to the north of this are areas of "terrace" country in which the seam is either close to the surface or at no great depth.

Pura Stream.—A "terrace" 60 chains up Pura Stream is 20 chains long and 24 chains deep. It contains two seams, separated by 10 ft. to 15 ft. of sandstone, the lower showing outcrops of not less than 6 ft. of coal and the upper 3 ft. An attempt to mine this area in the past was abandoned. The Mines Statement for 1933 records that at the Fernbrook Mine "a seam of coal 6 ft. thick is being developed on a level course to the north. The coal is of good quality . . ." Barometric heights give a maximum overburden, including the strata between the seams, of 95 ft. The "terrace" is really a dip-slope gently inclined to the north-west, so that the average overburden is not likely to be much less than the maximum. If there is 95 ft. of overburden and a total of 9 ft. of coal, the ratio of overburden to coal is 11·5 cubic yards per ton. Areas with such a high ratio have not yet been stripped in New Zealand and could not be economically worked with the available equipment; nor is the area large enough to warrant expenditure on the machinery necessary to handle the spoil to the best advantage. One or two prospect bores are warranted to establish whether the overburden ratio is as heavy as the reconnaissance suggests.

GEOLOGY OF COAL CREEK, ROSS

By H. W. WELLMAN, N.Z. Geological Survey, Department of Scientific and Industrial Research

[*Received for publication, 7th May, 1945*]

Summary

A brief description of the stratigraphy and structure of the area about Coal Creek, Ross, is given. The coal-measures at the base contain bands of white quartz sands. These are described in some detail, and the amount that can be economically stripped is estimated.

In the appendix is set out the work carried out in the Dominion Laboratory on the sand, which is not suitable for glassmaking, but may have value as a moulding-sand.

LOCALITY

DONNELLY CREEK is a large stream that flows north from Mount Greenland past the Township of Ross to the Totara River about a mile from the sea. Coal Creek is a small, west-flowing tributary of Donnelly Creek, which it joins half a mile south-east of the Ross–Hokitika Road. The road to the Ross Lime-quarry leaves Ross opposite the post-office and crosses Donnelly Creek by a bridge 20 chains from the mouth of Coal Creek. From the lime-quarry road a foot-track follows the side of a water-race leading from Donnelly Creek opposite the mouth of Coal Creek; to this point road-construction would be easy. The construction of a road up Coal Creek would be less easy, but not difficult, for the flat valley floor has been worked for gold and is now covered with moderate-sized tailings.

Although the valley of Coal Creek has been extensively worked for gold and was once cleared, the bush has since advanced to the mouth of the stream.

STRATIGRAPHY

There are few exposures in the bed of Coal Creek, but the valley walls which flank the flat bottom of the stream are steep, and solid rock is close to the surface for considerable distances. Near the mouth of Coal Creek on the east side of Donnelly Creek soft, steeply dipping glacial silts are well exposed, and similar material is poorly exposed in the lower part of Coal Creek. A few chains farther upstream the valley walls become steeper, and fossiliferous Waitotaran sands and silts can be seen, these beds being nearly vertical and striking at 50°. The contact between the Waitotaran beds and the glacial silts was not seen. The fossils are extremely poorly preserved, consisting of soft casts only. The contact between the sandstone and the limestone that crosses the creek 7 chains upstream from its mouth is not exposed in the creek itself, but outcrops of the limestone and sandstone closely adjoin in the steep north valley side, and a shallow excavation exposed the actual contact, which shows a smooth but undulating surface of limestone separated from the sandstone and siltstone by a narrow band of sandy conglomerate. This conglomerate is composed almost entirely of fragments of high-grade schist and granite similar to that now exposed near the Alpine Fault, which, at its closest, is ten miles east of Ross. The limestone dips south at 35° ; its exposed surface is almost vertical and closely parallel to the bedding of the overlying sandstone, which strikes north-east. The interpretation of this contact is not easy, but as there is no evidence of slickensiding or crushing of the limestone, and as the limestone is immediately overlain by the sandy conglomerate, which is different from the sandstone higher in the sequence, it seems probable that it is an unconformable sedimentary contact, but unusual in that the older beds are now less tilted than the younger ones. The structure according to the above interpretation is shown in the cross-section.

Limestone.—No complete section through the limestone was seen, but the following description, which is deduced from scattered outcrops and loose blocks, is probably substantially correct. The upper part of the limestone is of good grade and similar to that worked in the lime-quarry 20 chains to the north. The middle part farther up the creek is more impure, darker in colour, and contains scattered grains of glauconite. Both the upper good-grade and the lower dark limestone contain not infrequent fossils, which do not weather out and cannot be easily separated from the hard matrix ; a collection (G.S. 3480) is described later. The limestone covers an area of about 50 acres north of Coal Creek, and has been mapped as far north as the head of Hodson Brook by Morgan (*N.Z. Geol. Surv. Bull. 6*, p. 104). It is being extensively worked for agricultural lime in the Ross Lime-quarry.

Greensand.—The calcareous glauconite below the limestone also contains macrofossils and is soft enough to make it practicable to wash for foraminifera. A sample was examined by Dr. Finlay, but the faunule is too poor to give a precise age determination.

A noticeable feature of the greensand is the borings, about half an inch in diameter, that extend through the whole mass of the material. The lower part of the greensand is exposed in a slip on the south side of Coal Creek almost opposite the mouth of the small branch stream, 30 chains from Donnelly Creek, in which the quartz sand was sampled, and can be seen to grade into coarse glauconitic sandstone. This material is deeply weathered but contains a few macro-fossils (G.S. 3481, 3482). The sandstone exposed in the slip appears nearly horizontal, and a small outcrop of muddy coarse sandstone at creek-level must be at least 50 ft. below the base of the greensand. The greensand is comparatively soft and does not form conspicuous

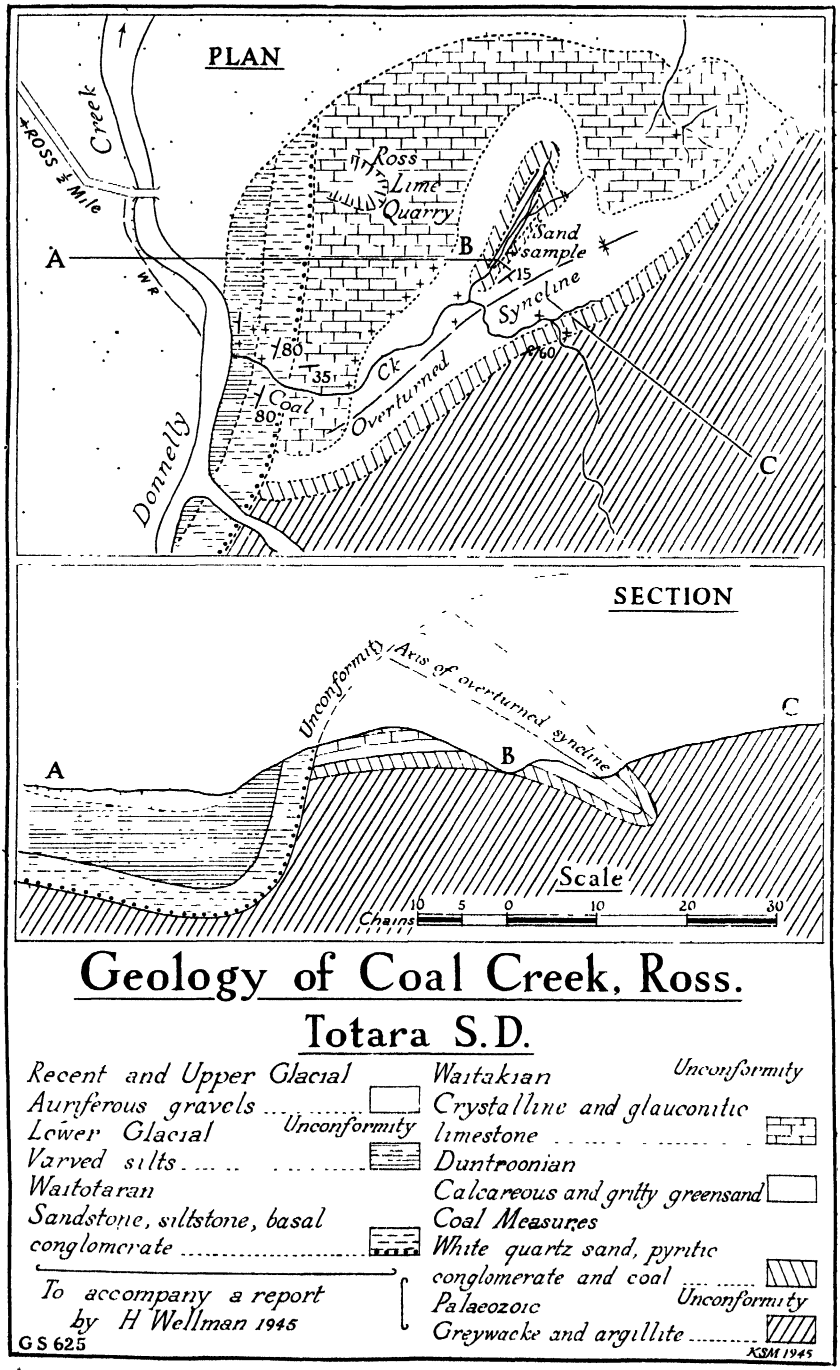

PLAN
Creek
ROSS ½ Mile
Ross
Lime
Quarry
A
B
Sand
sample
15
Syncline
Ck
Overturned
80
35
Coal
80
60
C
Donnelly
SECTION
A
Unconformity
Axis of overturned syncline
B
C
Scale
Chains
10 5 0 10 20 30
Geology of Coal Creek, Ross.
Totara S.D.
Recent and Upper Glacial
Auriferous gravels
Lower Glacial
Unconformity
Varved silts
Waitotaran
Sandstone, siltstone, basal conglomerate
To accompany a report by H Wellman 1945
G S 625
Waitakian
Unconformity
Crystalline and glauconitic limestone
Duntroonian
Calcareous and gritty greensand
Coal Measures
White quartz sand, pyritic conglomerate and coal
Palaeozoic
Unconformity
Greywacke and argillite
KSM 1945

FIG. 1.

outcrops; it was seen *in situ* at only a few places, but has been mapped as extending over a considerable area between the limestone and the coal-measures.

Coal-measures.—The beds immediately beneath the coarse sandstone are well exposed in the branch stream. They consist of dark pyritic sand with bands of sub-angular pebbles of quartz, and rest on the white quartz sand, which is described in greater detail later. The base of the Tertiary beds is not as well exposed in the branch creek as it is in a slip on the south side of Coal Creek a few chains above the junction of the small tributary. In this slip, although the coal-measures have been overturned and now dip to the south, being apparently overlain by greywacke, they are not crushed and the sequence is clear. The white quartz-sand beds have about the same thickness as in the branch creek and are underlain by carbonaceous sands and clay and an impure seam of coal no more than 3 ft. in thickness. The base of the coal-measure rests on greywacke which is both weathered and crushed. Approximate analysis of the coal made by Mr. W. Doherty, of the State Mines Department, Greymouth, is as follows:

Moisture	12·2
Volatile matter (non-coking)	29·0
Fixed carbon	39·3
Ash	19·5
	100·0

The sample of coal analysed may have been sufficiently weathered to increase slightly both the moisture and volatile content.

The greywacke and argillite under the coal-measures are exposed at the top of the slip in Coal Creek and in several places in the branch creek. They form the undermass in the Ross district, are many thousand feet thick, and were intensely deformed before the deposition of the coal-measures. Wherever seen, the undermass is severely crushed, and is in places so pulverized that it now forms a tight pug which surrounds the less-crushed fragments. The coal-measures, even where overturned, are not crushed and show little internal evidence of the deformation to which they have been subjected.

AGE OF BEDS

The macro-fossils have been examined by Dr. Marwick, who writes as follows:—

G.S. 3479.—Leached soft sandstone. Coal Creek, 5 chains from Donnelly Creek.
Maorimactra sp.
Antisolarium sp.
Only casts remain, but since both forms are common in the Waitotaran of Hokitika district, they can be taken to indicate a Waitotaran age for these beds also.

G.S. 3480.—Hard, blue-grey, sandy limestone.
Serripecten n.sp.
? *Marama* sp.
Panopea worthingtoni Hutton.
In addition, a fragment of Octocorrallian coral, *Graphularia*, and Echinoid fragments were collected. The *Serripecten*, which is smooth in the juvenile and has rather smooth radials in the adult, suggests an age either Whaingaroan or Duntroonian. *Graphularia* is known from Upper Kaiatan to Waitakian. The age, therefore, is probably Whaingaroan or Duntroonian.

G.S. 3481.—Calcareous, gritty greensand.
Serripecten n.sp. as at 3480.
? *Lima* n.sp., small, subequilateral.
Since the *Serripecten* is much the same as at 3480, the respective beds probably belong to the same stage.

G.S. 3482.—Reddish, weathered, glauconitic, coarse sandstone.
Chlamys n.sp., 28 broad, close ribs.
Lima n.sp., small, inequilateral.
The nearest known relative to the *Chlamys* is a species with less than 20 ribs from the Kaiatan, G.S. 3171, Perpendicular Point. The *Lima* differs from that at G.S. 3481.

STRUCTURE

It will be seen from the plan and cross-section that the structure of the rocks in the valley of Coal Creek is unusually complex. The correctness of the interpretation of the section depends almost entirely on the nature of the contact between the Waitotaran sandstone and the Waitakian limestone. If this contact has been correctly interpretated, then it appears that the lower Tertiary beds were intensely deformed at some time in the middle Tertiary. The erosion that followed stripped the lower Tertiary rocks from most of the area, but the syncline at Coal Creek was below base level and escaped destruction. During the late Tertiary and early glacial period, marine and fresh-water deposits were laid down on the erosion surface that truncated the folds in the early Tertiary beds, and extended indifferently across both the greywacke undermass and the upturned edges of the early Tertiary beds. These younger beds, together with the older Tertiary strata, were later folded and eroded, and on them were deposited late Tertiary and Recent gravels.

QUARTZ SAND

The following detailed section through the quartz sands was measured and sampled on the east side of the branch creek 5 chains above its confluence with Coal Creek:—

	Ft
Dark pyritic coarse sand with narrow bands of sub-rounded quartz pebbles, few argillite pebbles, less than 3 in. across	8
Medium white quartz sand (sample 1)..	4
Dark pyritic fine sand	4
White quartz sand (samples 2 and 3)	8
Dark band with mica and granules of quartz	1
White quartz sand (sample 4)	7
Dark pyritic band	2
White quartz sand (sample 5)	9
Darkish clayey sand	3
White quartz sand (sample 6)	11
Clayey sand	4
Bottom of section, stream-level.	

The irregular deformation of the adjoining area is reflected by the minor irregularities in the attitude of the sand bands, which show several dislocations with a throw of a few inches and vary considerably in attitude over short distances. At the top of the section described above, the conglomerate band dips to the south-east at 15°; but only 50 ft. distant the well-defined surface of the 2 ft. dark bands dip in about the same direction at 40°; still lower in the section the beds again flatten. The variation in attitude described above is unlikely to be depositional, and it is probable that similar or even greater variations will be found in all parts of the area.

The greywacke undermass is unlikely to be more than 50 ft. lower than the base of the measured section, for crushed greywacke is exposed in the bed of the stream less than a chain away.

Quantity of the Sand.—It will be seen from the detailed section that the aggregate thickness of the bands of quartz sand is 40 ft. The sand, together, with the overlying beds, dips to the east away from the branch creek, and the amount of overburden will increase rapidly away from the outcrop. Only a narrow band of sand, assumed as 30 ft., can be economically stripped. The length of the outcrop on the east side of the branch creek is about 10 chains, so the quantity of sand available is at least 10,000 tons.

Quality.—It will be seen from the detailed section that darker impure bands, which were not sampled, are interbedded with the white sand. The impure bands will certainly make the sand more difficult to work, but as the bands are well defined it would be possible to separate them.

The sand is fairly compact, and usually weathers to form vertical faces.

APPENDIX

LABORATORY INVESTIGATION

By L. R. L. DUNN, F. T. SEELYE, and J. J. CORNES, Dominion Laboratory

White Quartz Sands, Coal Creek, Ross

Analyses.—The samples were examined for possible value as glass-sands or moulding-sands.

Grading Tests.—The sands were sieved dry into the following grades :—

Gravel : Particles greater than 2 mm. diameter.
Very coarse sand : Particles 1 mm. and 2 mm. diameter.
Coarse sand : Particles 0·5 mm. and 1 mm diameter.
Medium sand : Particles 0·25 mm. and 0·5 mm. diameter.
Fine sand : Particles 0·1 mm. and 0·25 mm. diameter
Superfine sand : Particles 0·25 mm. and 0·1 mm. diameter.
Silt and clay : Particles 0·05 mm. and less.

NOTE The silt-and-clay fraction represents that fraction passing a No. 300 British Standard sieve when washed through with a stream of water.

Grades	L. 123-1 Sample 1	L. 123-2 Sample 2	L. 123-3 Sample 3	L. 123-4 Sample 4	L. 123-5 Sample 5	L. 123-6 : Sample 6
A. Gravel (per cent.) ..	0·1	0·6	0·1	0·7	Nil.	Nil
B. Very coarse sand (per cent.)	0·4	9·8	4·7	10·1	0·2	0·3
C. Coarse sand (per cent.)	2·8	28·5	20·9	19·9	19·5	19·9
D. Medium sand (per cent.)	30·5	20·0	25·5	20·2	28·3	31·9
E. Fine sand (per cent.)	30·6	16·9	22·8	13·2	22·3	21·1
F. Superfine sand (per cent.)	19·6	14·3	14·0	16·6	16·9	14·9
G. Silt and clay (per cent.)	16·0	9·9	12·0	14·3	12·8	11·9

Chemical Analyses.—A complete chemical analysis was made of the mixed glass sand grades obtained by sieving (grades C, D, and F) from L. 123-2, which by microscopical examination appeared to be the best sand of the series from the purity standpoint. Partial and approximate analyses of similar grades were made of L. 123-3, L. 123-4, L. 123-5, and L. 123-6.

The results were :—

——	L. 123-2	L. 123-3.	L. 123-4	L. 123-5.	L. 123-6.
SiO_2 (per cent.) ..	98·04	..	..	..	..
Al_2O_3 (per cent.) ..	0·99	2·1	1·9	1·3	1·7
Fe_2O_3 (per cent.) ..	0·07				
TiO_2 (per cent.) ..	0·03	..	..	..	..
CaO (per cent.) ..	0·12	..	..	..	..
MgO (per cent.) ..	0·15	..	..	..	..
Na_2O (per cent.) ..	0·06	0·06	0·03	0·03	0·04
K_2O (per cent.) ..	0·39	0·69	0·45	0·39	0·42
Loss on ignition ..	0·20	..	..	..	..
	100·05				

Utility as Glassmaking Sands.—For glassmaking the main requirements are high silica content, low iron content, and correct grading. The bulk of the sand should consist of medium and fine sand grades. Preferably the sand should have at least 70 per cent. and, if possible, 90 per cent. of one grade, and this grade should in most cases be medium sand.

In the latest specification for sands for making colourless glasses (see *J. Soc. Glass Tech.*, *27*, No. 123 (1943)) it is specified that the combined superfine sand and silt and clay grades shall not exceed 5 per cent.

The purity of the sand is fixed according to which of the following three classes of glassware is to be manufactured from it :—

Class of Glassware.	Minimum SiO_2 Content	Maximum. Fe_2O_3 Content.
(*a*) Fine optical glass	99·0	0·008
(*b*) High-grade domestic and decorative glassware	99·0	0·02
(*c*) General colourless glassware, including containers ..	98 5	0·04

Conclusions.—The above requirements are not satisfied with any of the samples. Grading is very unsatisfactory and there is too much superfine sand and clay present.

Even if it were found feasible to classify the sands into the glass grades, it is doubtful if even the best of the samples would be good enough for glassmaking. Due to the presence of muscovite, the alumina content is generally too high, and the silica content is below the desirable minimum. The iron content varies, but is too high in all samples for colourless glass.

Use as Moulding-sands.—While for glassmaking a sand of uniform grain-size is desirable, the opposite is the case with moulding-sands, where distribution of grain-sizes is necessary, and also clay is required as a bonding agent.

The requirements for moulding-sands are given in a paper by L. R. L. Dunn, in *N.Z. J. Sci. and Tech.*, *10*, 74 (1928).

The clay contents of the sands were determined according to the method outlined in the above paper and the percentages of the silt and sand grades worked out approximately from the table of grading of the glass sands : -

——	L. 123-1.	L. 123-2.	L. 123-3.	L. 123-4.	L. 123-5	L. 123-6.
Retained on 60-mesh ..	33·8	58·9	51·2	50·9	48·0	52·1
Retained on 300-mesh	50·2	31·2	36·8	34·8	39·2	36·0
Silt grades (less clay) ..	10·9	8·6	10·5	11·9	11·5	10·4
Clay	5·1	1·3	1·5	2·4	1·3	1·5

Except for L. 123-1, the samples generally contain insufficient clay bond for use as natural moulding-sands. In addition, they are much too coarse in grain for ordinary brass- or even iron-foundry work. There is, of course, the possibility of use after separating into suitable grades, and recombining according to the type of moulding-sand required, with addition of bentonite or other clay to provided the necessary bond.

VANADIUM IN THE TARANAKI TITANIFEROUS IRON-ORES

By C. OSBORNE HUTTON, Petrologist, Geological Survey, Department of Scientific and Industrial Research

[*Received for publication, 7th June, 1945*]

Summary

The significance of the mineral coulsonite is discussed, and a re-examination of polished surfaces of some titaniferous magnetites gives no indication of the existence of coulsonite in these ores. The apparent affinity of vanadium for magnetite rather than for ilmenite is discussed on the basis of the size of the ions concerned, but it is believed that this association is due to the retention of vanadium in residual magmatic liquids after ilmenite has crystallized.

A RECENT investigation by the writer of some titaniferous iron-ores from the New Plymouth district has shown that the chief ore mineral is titano-magnetite, although a very minor amount of titanhematite is present as individual grains and also as an "intergrowth" with some of the titano-magnetite; it was suggested by the author (Hutton, 1945, p. 297) that the occurrence of the titanhematite in the latter case was probably due to exsolution as a result of the very limited solid solution that is known to exist between hematite and magnetite (Greig, Posnjak, Merwin, and Sosman, 1935). Small, but very constant, amounts of vanadium up to 0·4 per cent. have been found in these titaniferous iron-ores, and, although the exact location of this element has not been proved, it was suggested by the author that the vanadium can only occur in the lattice of the magnetite, as no indication of a distinct vanadium-bearing mineral was observed in these sands.

When this statement was made the writer did not fully realize the significance of the mineral coulsonite (Heron, 1936; Dunn and Dey, 1937) as applied to the Taranaki ironsand ores. Coulsonite, originally described as vanado-magnetite by Heron, is an important constituent of titaniferous iron-ores genetically associated with a series of basic and ultrabasic intrusives situated near the southern border of the Dhalbhum Subdivision of Singhbhum, Bihar Province, India. The properties of coulsonite as observed in reflected light are, according to Dunn and Dey (1937, pp. 131–132), identical with those of maghemite, and it can only be distinguished from the latter by microchemical tests for vanadium; furthermore, these authors observed that its diagnosis is difficult, if not impossible, except at high magnifications.

A restudy of the Taranaki ore was undertaken in order to determine if the vanadiferous mineral could be recognized, and further, if this mineral could not be detected, to try and decide on the location of the vanadium in the ore. Apart from the titanhematite laths, no indication of any other exsolution features were observed under a high magnification, and therefore it is only reasonable to assume that at least the major proportion of the 0·39 per cent. of V_2O_3 present in the titanomagnetite must be situated within the lattice of that mineral. On the other hand, it had been previously noted that some very minute lens-like bodies occurred within the titan-hematite itself, and it was suggested that these features might be the mineral maghemite, or else merely twinning on a very minute scale brought about

by stress. A vanadium determination carried out by Mr. F. T. Seelye showed that the titanhematite itself contained 0·30 per cent. of V_2O_3—that is, slightly less than the amount of vanadium previously found to be present in the titanomagnetite (Hutton, 1945); the writer does not believe that this difference has any real significance. Repeated attempts to obtain some powder from one of these lens-like bodies resulted in failure, but it is suggested that, in view of the similarity of the ionic radii of V^{3+} and Fe^{3+}, fairly complete solid solution may be expected. Any separation of a vanadous-rich phase from titanhematite containing only 0·30 per cent. of V_2O_3 would suggest an extremely limited degree of miscibility, and this does not seem warranted; furthermore, the presence of a small amount of V_2O_3 in some Indian hematite that showed no trace of a separate coulsonite phase on examination of polished surfaces is in direct support of this contention (Dunn and Dey, 1937, p. 136). Dunn and Dey point out that coulsonite is associated with magnetite and not with ilmenite in the ores of the Singhbhum area, whereas a similar feature has been noted in the ores of Parry Sound, in the district of Ontario. No evidence pointing in that direction has been recognized yet for the New Zealand ores, as free ilmenite has not been recognized in Taranaki ironsands so far. In their discussion on this point Quirke and Kremers (1943, p. 180) take into consideration the relative sizes of the ions of Ti, Fe, and V in various degrees of ionization, but in the writer's opinion they place undue weight on the fact, that the size of the V^{3+} ion is closer to that of Fe^{3+} than it is to Ti^{4+}; but the difference is so slight that it is very doubtful whether vanadium would always replace trivalent iron and completely disregard tetravalent titanium, instead of being distributed between these two elements. If a strict limitation of vanadium to the magnetite molecule does exist, and it would seem as if this were so, then some other factor or factors of the utmost importance influence this arrangement. In addition to some selection according to the size of the ions, Quirke and Kremers believe that the association of coulsonite with magnetite rather than with ilmenite is due partly to the retention of the vanadium in the residual magmatic liquids long after the completion of the ilmenite crystallization period. The present writer believes that this is the *main* reason for this association of vanadium in titaniferous iron-ores.

REFERENCES

DUNN, J. A., and DEY, A. K. (1937): Vanadium-bearing Titaniferous Iron-ores in Singhbhum and Mayurbhanj, India. *Trans. Min. Geol. Inst. India*, *31*, 117–194.

GREIG, J. W.; POSNJAK, E.; MERWIN, H. E.; and SOSMAN, R. B. (1935): Equilibrium Relationships of Fe_3O_4, Fe_2O_3, and Oxygen. *Am. J. Sci.*, *30*, 239–316.

HERON, A. M. (1936): General Report for 1935. *Rec. Geol. Surv. India*, *71*, 44.

HUTTON, C. O. (1945): The Ironsands of Fitzroy, New Plymouth. *N.Z. J. Sci. & Tech.*, *26* (Sec. B), 291–302.

QUIRKE, T. T., and KREMERS, H. E. (1943): Rare Element Prospecting in Pegmatites. *Econ. Geol.*, *38*, 173–187.

ACTIVITY AT RUAPEHU, MARCH–APRIL, 1945

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Summary

Recent activity at Ruapehu is described, the most notable feature being the formation and disappearance of a cone (tholoid) in the Crater Lake.

INTRODUCTION AND GEOLOGY*

RUAPEHU, rising above the central plateau of the North Island (2,300–3,000 ft. above sea-level) to a height of 9,175 ft., is the highest and most southerly of a number of active, dormant, or recently extinct volcanoes forming a zone trending in a north-easterly direction to White Island (Fig. 1)—the "Taupo Zone" of Hochstetter (1864, pp. 92–95). Eleven miles to the north is the multiple volcano, Tongariro, with an active cone, Ngauruhoe (7,515 ft.).

From Pliocene times Ruapehu has been built up of successive lava-flows with showers of scoria and ash, and the latest flows of dark-coloured andesite extend far down into the valleys. The broad irregularly shaped summit (Fig. 1) includes two or possibly three craters ; these are distinguished as "North" and "South" by B. Friedlaender (1899, pp. 507-509), and as "West," "East," and "Girdlestone" by L. I. Grange and J. H. Williamson (1929–30, p. 12). This summit outline is considered by some (Speight, 1908, p. 9 ; Grange and Williamson, 1932–33, p. 21) to have resulted largely by removal of the top part of an original cone by explosion, but truncation need not necessarily have occurred (Friedlaender, 1899 ; Cotton, 1944, p. 231). Near the eastern edge of the "South" crater is Crater Lake, a circular basin approximately 30 chains in diameter, normally bounded on the south and west by vertical ice cliffs, on the north by lava, and on the east by scoria rising to a peak 250 ft. above lake-level. Water percolating through the eastern scoriaceous wall probably forms the source of the Wangaehu River. Mud-flows (Lahars) from Ruapehu, accounting for the presence of mounded fields at the base of the volcano (Grange, 1931), have formed vast accumulations of volcanic conglomerate, large boulders being transported up to forty-eight miles (Cotton, 1944, pp. 244–246).

PREVIOUS ACTIVITY

Except for a mud-flow, which apparently swept down the Wangaehu River in 1869 or earlier (Crawford, 1869, p. 354 ; Cussen, 1887, p. 379 ; Grange and Williamson, 1932–33, p. 21), outbursts within historical records have been confined to the Crater Lake, the presence of which may mask to some extent the activity of Ruapehu (Friedlaender, 1899, p. 509). In 1886 (Park, 1887, p. 330) and 1926 (Thomson, 1926, p. 357) the lake was ice covered, but normally the acid, chalky-green water is warm and emits a sulphurous smell. Steaming of the lake or eruptive bursts of steam, mud, and ash have been reported at irregular intervals. A list, probably incomplete as no regular observations have been made, is : 1869 ; March, 1881 (Cowan, 1927, pp. 72, 149) ; April, 1886 (Cussen, 1887, p. 378) ; May, 1889 ;

* For detailed accounts of geology, see R. Speight (1908), L. I. Grange and J. A. Hurst (1928–29), and L. I. Grange and J. H. Williamson (1929–30, 1932–33).

March, 1890 (Hill, 1892); March, 1895 (Dunnage, 1895, and Hill, 1896); 1896 (Lowe, 1896-97); 1897 (Friedlaender, 1899, p. 507); March, 1906 (Speight, 1908, p. 9); October, 1921 (the *Dominion*, Wellington, 5th October,

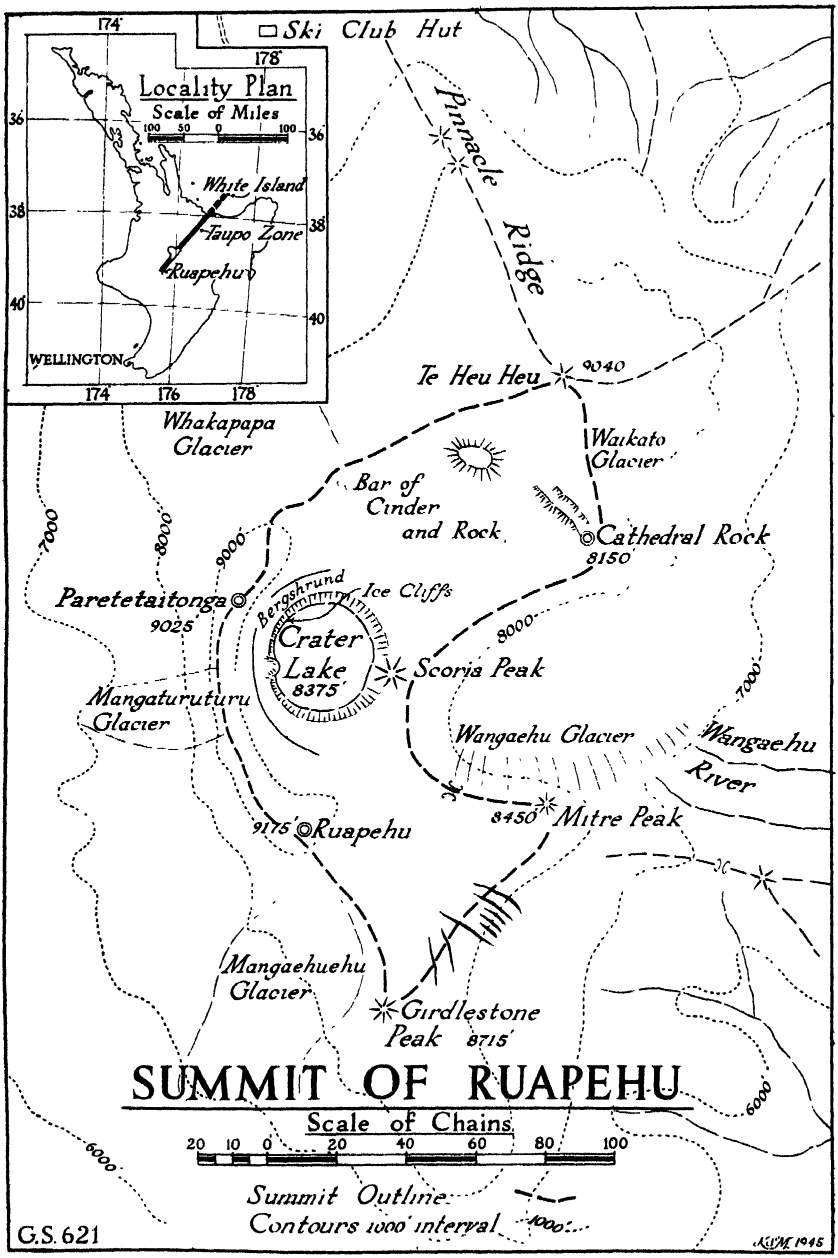
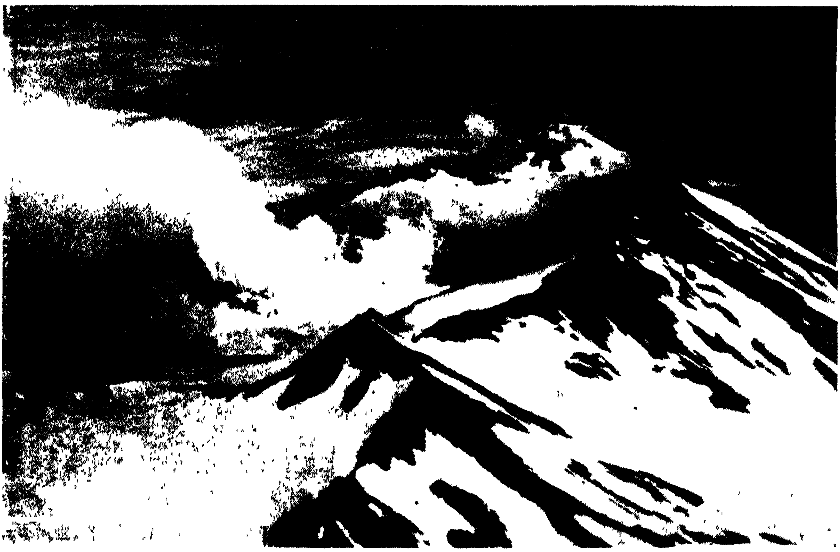


FIG. 1.—Map of the summit of Ruapehu. Inset, locality map.

1921); August, December, 1934; February, 1935; May, 1936; April, 1940 (the *Evening Post*, Wellington, 29th April, 1940); October, 1944 (Visitors' Book, Ruapehu Ski Club).

PRESENT ACTIVITY

The latest activity, which was again confined to Crater Lake (Fig. 2), began on the 8th March, when a long plume of steam was noted blowing east from Ruapehu, the eastern slopes of which were covered by mud and ash. Definite evidence of the emergence of a new cone, the outline of which was usually obscured by rising steam (*cf.* Figs. 3, 4, 5, and 7), was obtained on the 19th March. Eruptions of steam and smoke from the cone (Figs. 5 and 7), which were accompanied by loud rumbling or crackling noises and by the discharge of mud, ash, and occasionally larger fragments, alternated with quieter periods of steam effusion. At 1.15 p.m. on the 26th March a very large explosive burst, comparable except in colour with the paroxysmal eruptions from Ngauruhoe in 1926 and 1928 (see Grange, 1928), was seen by Mr. R. Ward, of Taupo, who estimated the column of steam to be between 6,000 ft. to 8,000 ft. high. This explosion was probably connected with the disappearance of the cone. One day later the writer reached the ski club's hut. No sign of the cone was observed, its former position being



[*R.N.Z.A.F. photo.*

FIG. 2.—Ruapehu, 9th March. Steam and smoke billowing from disturbance in Crater Lake. Photograph taken looking south-east; Paretetaitonga in foreground, Ruapehu Peak in background, Scoria Peak to the left of Crater Lake.

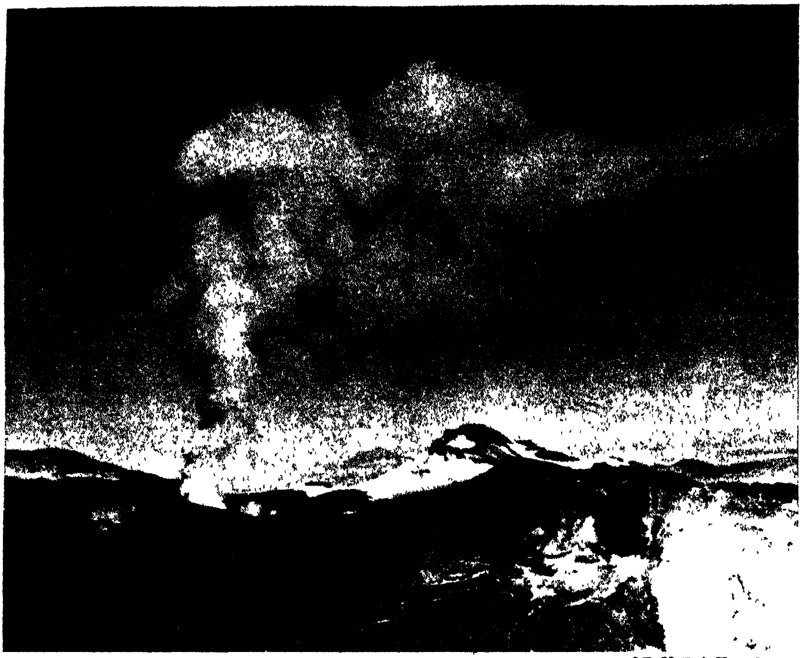
shown by the greatest concentration of steam rising from the lake. This steaming, accompanied by a strong sulphurous smell, has continued with infrequent eruptive outbreaks of steam, mud, and ash; the last outburst, reported on the 16th April after a quiet spell of fourteen days, rose thousands of feet above the crater.

The new cone was circular in outline, approximately 2 chains in diameter at water-level, and with a slightly convex surface broken by cracks through which steam issued (Fig. 6). Three types can be distinguished in the ejectamenta covering the summit snowfields (Figs. 4, 5, and 7):—

(*a*) Mud and ash, which constitute the bulk of the ejected material:

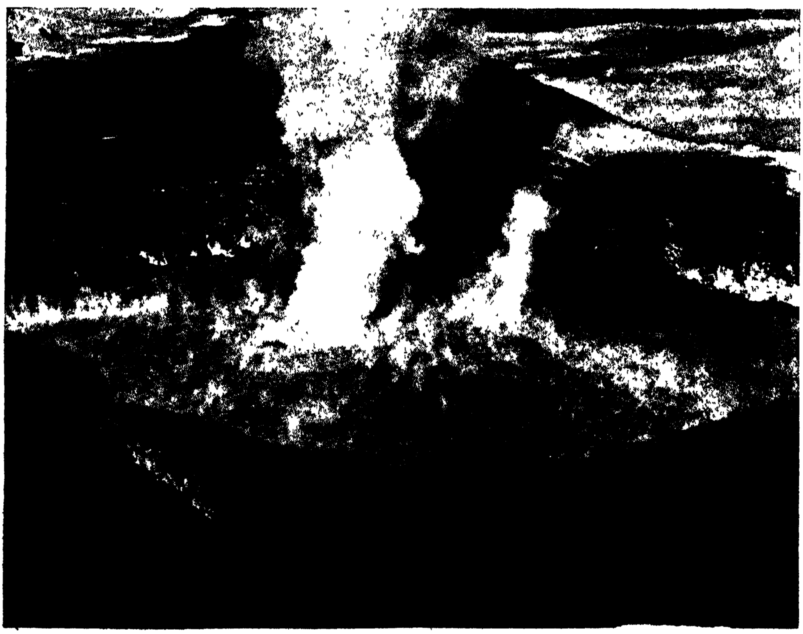
(*b*) Debris from the lake coated, or impregnated, with sulphur (P. 4922–4925)*:

* Numbers refer to specimens in the collection of the N.Z. Geological Survey.



[R.N.Z.A.F. photo

FIG. 3.—Ruapehu, 19th March. Steam rising from Crater Lake. Photograph looking north-west; Scoria Peak and Cathedral Rock in foreground, Paretetaitonga in central background.



[R.N.Z.A.F. photo.

FIG. 4.—Ruapehu, 29th March. Close up of Crater Lake showing cone covered by steam. Note steaming from surface of lake, the exposure of rock below the ice cliff at right, and the ash- and mud-covered snowfields in background.

(c) Hypersthene andesite (P. 4926–4928), presumably from a lava column in the cone.

It may be noted that (b) and (c) occur in blocks occasionally weighing several hundredweight, but generally much smaller ($<$ 6 in. in length). Although the disappearance of the cone below lake-level prevented confirmation, the above features indicate that the emerged cone was a tholoid or cumulo-dome similar to those commonly developed in the craters of andesitic volcanoes but rarely surviving as independent relief forms (Cotton, 1944, pp. 169–170). Hundreds, even thousands, of tholoids exuded successively at the summit, together with the immense amount of debris derived from them either by crumbling during growth or by explosive disintegration, are probably built into the body of a great andesitic cone (Cotton, *loc. cit.*).

[*National Film Unit photo.*

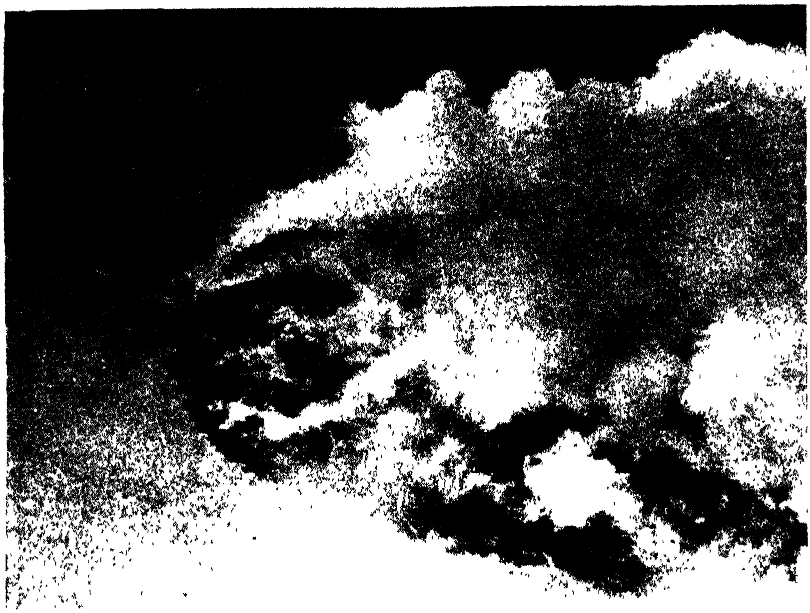
FIG. 5.—Ruapehu, 23rd March. Eruption from cone. Note crevasses and ash- and mud-covered surface in background.

Mr. J. A. Blyth, a close observer for twenty years, noted the following changes at the crater:—

(1) The lake-level has been lowered by 5 ft. to 8 ft., resulting in (a) the exposing of the crater wall beneath the north-west ice-cliff (Fig. 4); and (b) the wide extent of the rock ledge now extending slightly above water-level from under Ruapehu Peak, where descent into the lake is normally made, around to the northern end of Scoria Peak; the presence of this ledge may assist investigations at Crater Lake:

(2) Crevasses surrounding the Crater Lake and on Whakapapa Glacier have increased both in number and size; scoria is present under the large bergschrund below Paretetaitonga.

Since this paper was sent to the press an article by Professor C. A. Cotton has appeared (*N.Z. Science Review*, *3*, 3–4), and in this the theoretical aspects of the March activity are discussed.



[*National Film Unit photo.*

FIG. 6.—Ruapehu, 23rd March. A close-up of the emerged cone in the Crater Lake. Note circular outline and the slightly convex surface from which steam is rising.

[*National Film Unit photo.*

FIG. 7.—Ruapehu, 23rd March. Eruptive burst from cone. Note steaming of lake and ash-covered snowfield in background.

ACKNOWLEDGMENTS

Acknowledgment is made to the Public Works Department for enabling the writer to fly over Ruapehu on the 23rd March; to the Government National Film Unit for the use of a film taken during the flight; to the R.N.Z.A.F. for permission to publish Figs. 2, 3, and 4; and to Messrs. D. H. K. Ross and W. White for photographic assistance. Particular gratitude is expressed to Mr. J. A. Blyth and party, of Hawera, for arranging the use of the Ruapehu Ski Club Hut and for their assistance and companionship on the mountain from the 27th to 30th March.

REFERENCES

COTTON, C. A. (1944): "Volcanoes as Landscape Forms." Whitcombe and Tombs, New Zealand.

COWAN, J. (1927): "The Tongariro National Park, New Zealand." Wellington, New Zealand.

CRAWFORD, J. C. (1869): On the Geology of the Province of Wellington. *Trans. N.Z. Inst.*, *2*, 343–360.

CUSSEN, L. (1887): Thermal Activity in Ruapehu Crater. *Trans. N.Z. Inst.*, *19*, 374–380.

DUNNAGE, W. H. (1894–95): An Ascent of Mount Ruapehu. *Ann. Rep. Dept. Lands and Survey of N.Z.*, 102–103.

FRIEDLAENDER, B. (1899): Some Notes on the Volcanoes of the Taupo District. *Trans. N.Z. Inst.*, *31*, 498–510.

GRANGE, L. I. (1928): Eruption of Ngauruhoe, March, 1928. *Trans. N.Z. Inst.*, *10*, 143–147.

——— (1931): Conical Hills on Egmont and Ruapehu. *N.Z. J. Sci. and Tech.*, *12*, 376–391.

GRANGE, L. I. and HURST, S. A. (1928–29): Tongariro Subdivision. *Ann. Rep. Geol. Surv., Dept. Sci. and Ind. Research*, 5–8.

GRANGE, L. I., and WILLIAMSON, J. H. (1929–30): *Ibid*, 10–13.

——— (1932–33): *Ibid*, 18–21.

HILL, H. (1892): Ruapehu and Ngauruhoe. *Trans. N.Z. Inst.*, *24*, 603–625.

——— (1896): Ruapehu and the Volcanic Zone in 1895. *Trans. N.Z. Inst.*, *28*, 681–688.

HOCHSTETTER, F. VON (1864): Geologie von Neuseeland. *Reise d. Novara, Geol. Teil, 1 Bd.*, 92–95.

LOWE, H. J. (1896–97): Mount Ruapehu. *Ann. Rep. Lands and Survey of N.Z.*, 115–116.

PARK, J. (1887): Narrative of an Ascent of Ruapehu. *Trans. N.Z. Inst.*, *19*, 327–331.

SPEIGHT, R. (1908): In L. Cockayne's Botanical Survey of the Tongariro National Park. *N.Z. Parl. Paper, C.–11*, 7–12.

THOMSON, J. A. (1926): Volcanoes of the New Zealand-Tonga Volcanic Zone. *N.Z. J. Sci. and Tech.*, *8*, 354–371.

APPENDIX

DATA ON LATER ACTIVITY, MAY–JUNE, 1945 *

SINCE this paper was submitted for publication additional information has been received and is summarized herewith.

Renewed activity early in May (the *Dominion*, Wellington, 10th and 14th May) resulted in the re-emergence of a tholoid larger than that developed in March, and this now occupies about one-third of the Crater Lake; the tholoid has since remained above lake-level. Outbursts of steam, and ejection of mud and ash, have occurred periodically, and, further, a glow and even flames (the *Dominion*, 15th May) are reported to have been observed in the crater.

* For a full description of the activity, May–July, reference should be made to a paper by R. B. Oliver in this *Journal*.

FURTHER ACTIVITY OF MOUNT RUAPEHU, MAY–JULY, 1945

By R. L. OLIVER, New Zealand Geological Survey, Department of Scientific and Industrial Research, Wellington

[*Received for publication, 24th July, 1945*]

(See J. Reed's account in this issue of the March activity of Mount Ruapehu for a general introduction to the subject.)

9TH MAY TO 1ST JULY

THE present phase of Mount Ruapehu's activity was first reported on the 9th May. The island (reported earlier) had again appeared in the middle of the lake and had attained to a slightly greater size than had appeared in March and April. Rocks were ejected, but they all fell back into the lake, though finer ash was deposited on the outer slopes of the mountain down to a level of 4,000 ft.

On the 14th May activity was again reported, of a nature considerably more violent than the most vigorous of the March eruptions. Loud explosions accompanied the ejection of rocks, which had not then fallen beyond the boundaries of the crater.

At 8 p.m. on the 14th May flame shot 300 ft. above the summit of the mountain, and this was followed by a second flame, and this in turn by a tall, dark cloud. The flashes are reported to have illuminated the countryside like daylight.

During the week previous to the 1st July inhabitants of Ohakune (nine miles from the summit of Ruapehu) heard quite plainly the rumblings associated with the mountain's activity, and very fine sulphury powder fell in the town. This dust is probably of similar composition to that ejected by the 1906 eruption, the analysis of which is shown in Table I. The high percentage of sulphur present in this analysis conforms with the general sulphury appearance of the dust erupted during the recent eruptions.

STATE OF CRATER ON 1ST JULY

(For convenience, the basin containing the crater lake will be referred to as the crater.)

By the 1st July about half the circumference of the island in the crater was in contact with the crater wall. The amount of remaining lake-water on the south and south-west sides is shown in Figs. 2 and 3 respectively. The level of what lake-water remained appeared to be very low; the mud on the exposed lake-bottom is shown in Figs. 6, 7, and 8. The statement of Mr. Prichard, of the Public Works Department, that on the 28th July 50 cusecs water were gushing from the south-east fissure in the crater wall, instead of the usual 2–3 cusecs, indicates where at least some of the water had gone. The steam cloud shown in the centre of Fig. 4, near the head of the gully, and on the right centre of Fig. 5 is from the crater-lake water as it emerged from the fissure into the head of the Wangaehu Valley. The temperature of the crater-lake water was 137° F.

[R.N.Z.A.F. photo.

FIG. 1.—General view taken on 27th June of the summit of the west side of Mount Ruapehu showing the steam cloud rising from the crater

[R.N.Z.A.F. photo.

FIG. 2.—View taken on 28th June of the crater-lake basin showing steaming remnant of crater lake on left, and dense fumes in centre being emitted from central vent of tholoid.

The tholoid itself was noticeably flat on top, and definitely not dome-shaped as was apparently the case in March (see J. Reed's account in this issue of the March activity). The margin, however, was a steep face about 15 ft. in height above the lake; the centre of the tholoid was not much more, except for a small protuberance immediately surrounding the vent (Fig. 9).

NATURE OF ACTIVITY

Excluding the central vent, the margins of the tholoid appeared to be the most active. It is possible that the greater volume of steam emitted from the margin was due to the latter's contact with the waters of the crater lake, and that evaporation as steam is one of the ways in which the lake-water had disappeared. Fig. 6, however, shows steam emitted from a part of the tholoid not in contact with the lake-water, and also the large

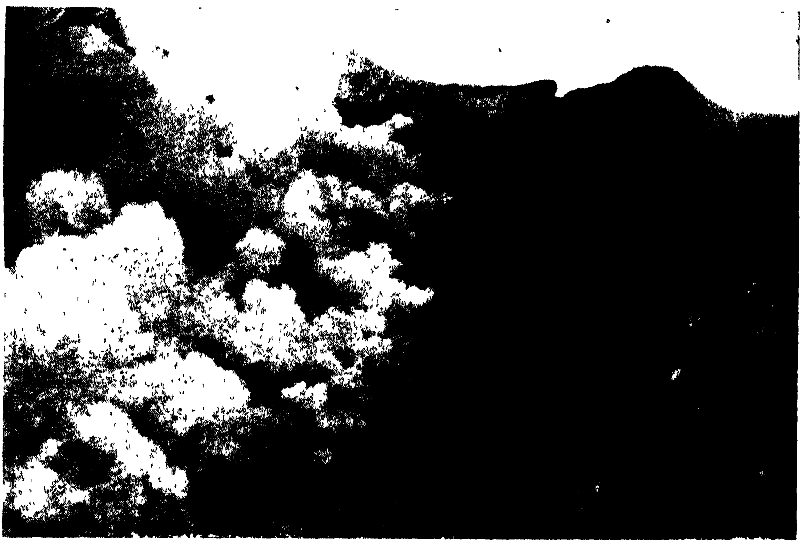


FIG. 3.—View taken on 1st July of margin of tholoid on south-west side, separated from wall of crater-lake basin by remnant of crater lake. Note crater walls covered with ash.

volumes of steam emitted from the central vent (Fig. 9) cannot have been derived from lake-water. The gases emitted from the tholoid had a strong sulphury smell, and the manner in which they were emitted is shown in Figs. 6, 7, and 8. They were emitted with considerable force from between the loose boulders forming the surface of the tholoid; also they bubbled out through the mud shown in Figs. 6, 7, and 8.

The surface of the tholoid consisted of loose angular scoriaceous boulders. An incomplete chemical analysis of one of these is shown in Table 2. Over most of the surface these appeared cold and dead, but the margin of the tholoid was definitely "alive." The loose scoriaceous boulders, averaging 2 ft. in diameter, were warm; on the steep face (Figs. 6, 7, and 8) the boulders were moving and heaving and falling as though due to pressure from behind—

evident testimony to the increasing size of the tholoid ; a red glow between some of the loose boulders on the surface at the margin of the tholoid also testified to its " live " condition. A similar glow was visible at night over the whole surface of the tholoid, but it is not clear whether this was emitted from between the boulders on the surface or from boulders themselves which had been ejected from the central vent.

The quiet emission of steam was the predominating form of activity, but in March (see J. Reed's account in this issue of the March activity) this alternated with " loud rumbling or crackling noises and by the discharge of mud, ash, and occasionally larger fragments." On the afternoon of the 1st July these more violent outbursts took place at intervals of fifteen or

[*R.N Z.A.F. photo.*

FIG. 4.—View taken on 28th June of head of Wangaehu Valley. The small steam cloud near the head marks the emission of the water from the crater lake.

twenty minutes, and the " larger fragments " (up to 5 ft. in diameter) were ejected at each outburst. These spectacular violent outbursts were from the central vent, and for about a minute rocks, ash, and steam were ejected with a terrific force, as though from a gigantic exhaust, and at the same time the surface of the tholoid surrounding the vent glowed like an immense brazier. The larger rocks were hurled to about the height marked by the point X in Fig. 10, and the steam cloud rose to a greater height than usual above the summit of the mountain. The outbursts commenced with a sudden bang, and the crackling, staccato roar (closely resembling the noise of a machine gun fired close to the ear) which continued made conversation impossible at the edge of the crater lake; it was the noise of these outbursts

[R N Z.A.F photo.

FIG. 5.—View taken on 27th June of steam from crater lake. The steam cloud on the right marks the emission of the water from the crater lake.

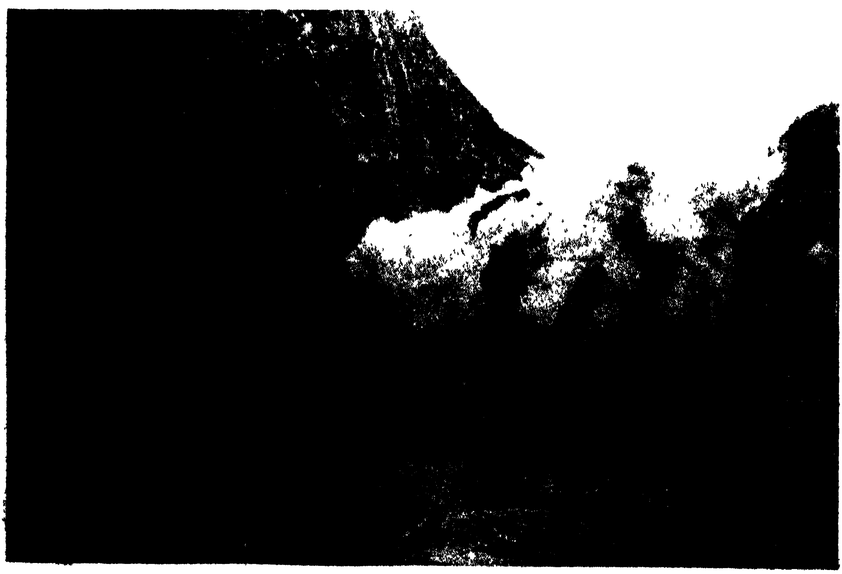


FIG. 6.—View taken on 1st July at crater-lake level showing margin of tholoid in contact with the crater wall (ice face). In the foreground is mud of the lake-bottom.

which could be heard as an avalanche-like rumble farther down the mountain-side. The rocks ejected by most of the explosions fell back on to the surface of the tholoid. Apart from these, the loose scoriaceous boulders on the surface were part of the solidified crust or carapace capping the tholoid or projected lava column. The closely pitted ice surface of the crater margin indicated that some of the boulders had been ejected more laterally.

The ejected rocks were of two main types—viz., a compact glassy hypersthene andesite, and an extremely vesicular pumiceous rock; the loose boulders forming the surface of the tholoid were of the latter type. An incomplete chemical analysis of these rocks is shown in Table 2. The finer sand which covered the slopes of the mountain down to a level of 4,000 ft. consisted of the components of the above-mentioned glassy hypersthene andesite, but the fine dust, which was deposited as far as nine miles from the crater (if it is the same as that ejected in 1906), contains, in addition, a considerable amount of sulphur (Table 1).

TABLE 1.—CHEMICAL ANALYSIS OF VOLCANIC DUST ERUPTED FROM MOUNT RUAPEHU, 1906

Silica	51·67
Alumina	13·55
Ferric oxide (Fe_2O_3)	6·04
Lime (CaO)	4·10
Magnesia (MgO)	2·19
Potash (K_2O)	1·47
Soda (Na_2O)	1·84
Titanium oxide (TiO_2)	0·59
Chromium oxide (Cr_2O_3)	Nil.
Sulphur	15·42
Carbonic anhydride (CO_2)	Nil
Loss on ignition	3·13
	100·00

TABLE 2

Incomplete chemical analyses of—

(1) Scoriaceous boulder from surface of tholoid of Mount Ruapehu, 1st July, 1945.

(2) Glassy hypersthene andesite ejected from crater of Mount Ruapehu, 1st July, 1945.

	(1)	(2)
Silica (SiO_2)	60·09	60·10
Phosphorus and alumina (P and Al_2O_3)	16·70	16·63
Ferric oxide (Fe_2O_3)	1·69	1·23
Ferrous oxide (FeO)	4·58	4·89
Magnesia	4·03	4·03
Strontia and lime (SrO and CaO)	6·89	6·88
Potash (K_2O)	1·83	1·81
Soda (Na_2O)	3·40	3·37
Manganous oxide (MnO)	0·10	0·10
Titanium dioxide (TiO_2)	0·70	0·70
Water (H_2O)	Very small.	Very small.
Phosphorous pentoxide (P_2O_5)	Amounts undetermined.	
Vanadium pentoxide (V_2O_5)	Amounts undetermined.	
Chromic oxide (Cr_2O_3)	Amounts undetermined.	
Nickel oxide (NiO)	Amounts undetermined.	
Sulphur (S)	Amounts undetermined.	
Chlorine (Cl)	Amounts undetermined.	

FIG. 7.—View taken on 1st July at crater-lake level showing the margin of the tholoid separated from the bottom of the crater wall by mud of the lake-bottom.

FIG. 8.—View taken on 1st July showing steep face of margin of tholoid. Lake-bottom mud in foreground.

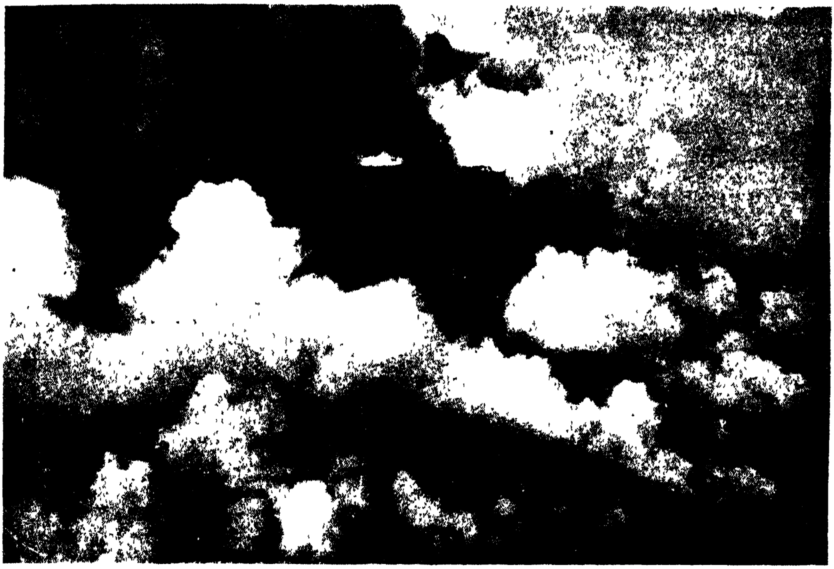


FIG. 9.—View taken on 1st July from crater-wall of centre of tholoid. Note the central vent marked by the emission of steam, and also the steam clouds near the margin of the tholoid.

FIG. 10.—General view taken on 1st July of steam cloud rising from the crater as seen from the summit of Ruapehu Peak. X marks the height to which large boulders were ejected during the more violent explosions.

COMPARISON WITH OTHER VOLCANOES, AND DISCUSSION

The nature of the activity has been "classified" by Professor C. A. Cotton (*N.Z. Science Review, 3*, No. 1, pp. 3 and 4, 1945). He considers that the Ruapehu activity is characteristic of the type which results in the uprising of a lava dome in the crater.

Some of the characteristics of such domes as outlined by Howel Williams and summarized by T. A. Jagger (*Volcano Letter 379*, 1932) are—

(1) The glassy nature and porphyritic structure of the lava. The non-scoriaceous lava ejected from Ruapehu is of this type.

(2) Up-welling of lava accompanied by explosions producing lava and tuff. The recent eruptions of Ruapehu conform with this.

(3) Rocks, are mostly andesites, rhyolites, and trachytes. The Ruapehu rock is an andesite.

(4) Intense solfataric action is seldom conspicuous. This does not conform with Ruapehu's activities. That this feature is exhibited by Ruapehu's activity is perhaps due to the presence of a crater lake; the steam might be the vaporized lake-water which has filtered into the margin of the tholoid.

(5) The rate of growth of the dome is rapid. The growth of the tholoid in the crater of Mount Ruapehu to its present size in two months compares favourably with the speed of growth of other domes.

(6) The gas content of the lavas is small—*e.g.*, 0·15 per cent. by weight of the andesites from Lassen Peak, and 0·10 per cent. of the andesites from an island in the Gulf of Santorin, Greece. An analysis of the gas content of the Ruapehu andesite has not been made.

F. A. Perrett (Eruption of Mount Pelée, 1929–32, Carnegie Institute Washington Publication, 1935) has divided domes into two types—viz., Closed Domes and Open Cones.

The Dome grows by additions of effusive lava oozing from a number of vents and subsequently breaking into blocks that slide down the flanks of the dome.

The Cone is built up by the accretion of clastic materials thrown out from an open central vent and falling in showers.

It would thus seem that the present activity of Mount Ruapehu is a combination of the above two types. Perret considers that dome or cone building characterizes the waning stages of activity.

— —

REFERENCES

COTTON, C. A. (1944): "Volcanoes as Landscape Forms." Whitcombe and Tombs, New Zealand.

——— (1945): Ruapehu in 1945. *N.Z. Science Review, 3*, No. 1, pp. 3 and 4.

JAGGER, T. A. (1932): A Summary of Features of Lava Domes, by Howel Williams. *Volcano Letter 379.*

PERRETT, F. A. (1935): "Eruption of Mount Pelée, 1929–32." Carnegie Inst. Washington Publn., No. 458.

EARTHQUAKES IN NEW ZEALAND DURING THE YEAR 1944

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[*Received for publication, 28th February, 1945*]

THE accompanying map shows the epicentres of earthquakes located in the New Zealand region, during the year 1944. Shocks with origins deeper than

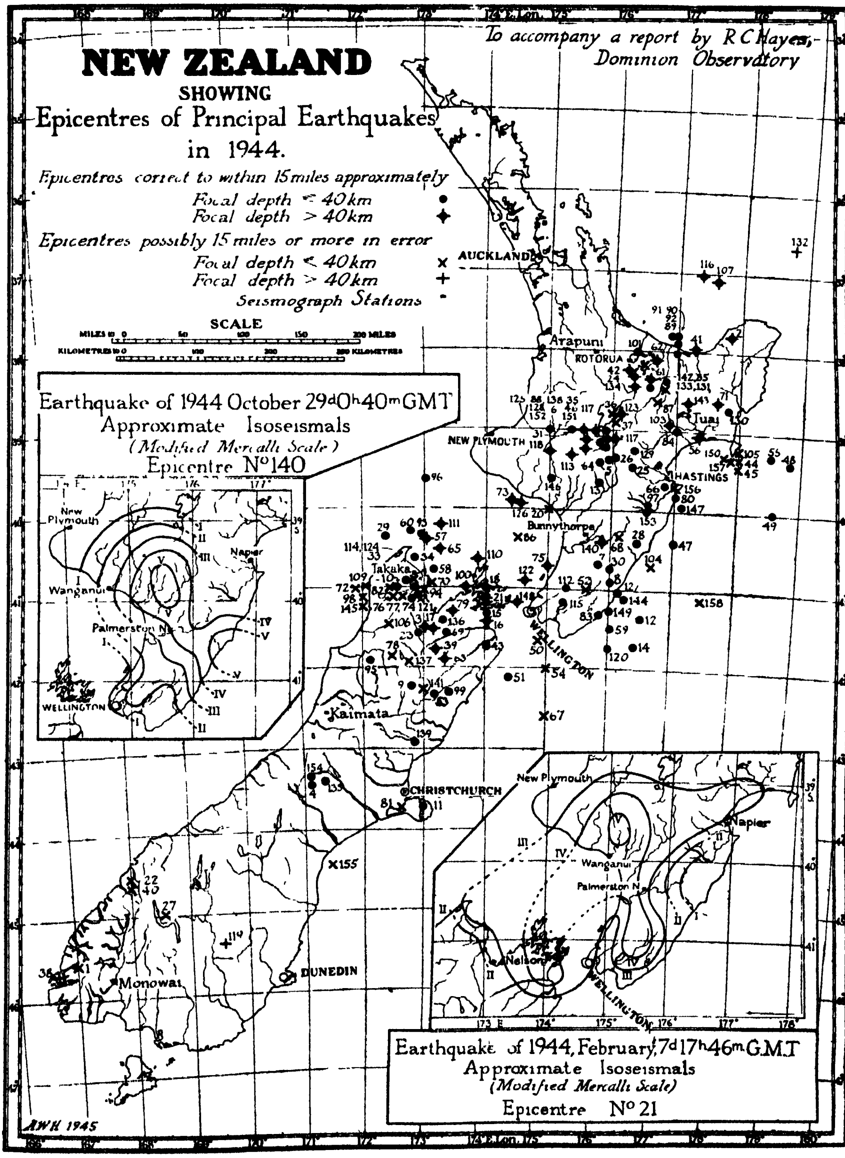

FIG. 1.

normal are indicated by distinctive symbols. Accuracy of epicentre determination is also indicated.

The inset maps show the approximate isoseismals of two of the most notable shocks during the year.

Some additional particulars of the earthquakes whose epicentres are shown on the main map, are given below :—

No.	Date and Time (G.M.T.) *				Maximum Felt Intensity (M.-M.)	No.	Date and Time (G.M.T.).*				Maximum Felt Intensity (M.-M.).
	1944.	d.	h.	m.			1944.	d.	h.	m.	
1	Jan. ..	4	04	09ca	III	52	Apr. ..	23	06	36·2	II
2	,, ..	5	18	15·2	..	53	,, ..	24	10	14·1	..
3	,, ..	6	09	43·4	..	54	,, ..	29	11	30·2	..
4	,, ..	6	15	42·6	..	55	,, ..	30	09	08·0	IV
5	,, ..	10	04	39·3	IV	56	May ..	9	13	25·5	III
6	,, ..	10	04	44·0	IV	57	,, ..	14	05	57·1	..
7	,, ..	12	13	54·1	IV	58	,, ..	16	07	24·6	IV
8	,, ..	13	22	19·4	V+	59	,, ..	17	08	53·5	II
9	,, ..	18	11	51·9	III	60	,, ..	20	18	39·7	..
10	,, ..	25	18	48ca	IV	61	,, ..	20	21	15ca	IV
11	,, ..	28	09	58·3	..	62	,, ..	21	12	13·7	..
12	,, ..	28	14	47·9	IV	63	,, ..	29	13	04 1	..
13	,, ..	29	06	39·9	..	64	,, ..	30	05	19·5	.
14	,, ..	29	09	25·6	III	65	,, ..	30	11	15·3	..
15	,, ..	30	03	51·3	III	66	,, ..	31	08	02·1	III
16	,, ..	31	02	51·7	III+	67	June .	1	07	39·8	..
17	,, ..	31	21	29·0	..	68	,, ..	1	12	40ca	II
18	Feb. ..	2	12	02·9	II	69	,, ..	3	04	01·0	..
19	,, ..	6	02	25·1	IV	70	,, ..	4	12	59ca	III
20	,, ..	6	14	45ca	II	71	,, ..	7	10	22·7	..
21	,, ..	7	17	46·4	V	72	,, ..	7	11	15ca	II
22	,, ..	12	05	29·5	II	73	,, ..	7	17	15 3	.
23	,, ..	13	04	04·4	..	74	,, ..	9	03	04·2	II
24	,, ..	15	00	38·2	..	75	,, ..	9	15	39·2	III
25	,, ..	16	02	13·1	..	76	,, ..	9	20	14ca	III
26	,, ..	19	17	23·1	IV	77	,, ..	11	00	56·0	II
27	,, ..	20	16	21ca	II	78	,, ..	14	23	42ca	IV
28	,, ..	25	03	30·0	II	79	,, ..	16	06	39·6	?
29	,, ..	26	23	28·9	..	80	,, ..	17	04	47·0	..
30	,, ..	27	06	43·0	IV	81	,, ..	21	14	00·4	I
31	Mar. ..	14	05	12·2	..	82	,, ..	21	22	57·7	I
32	,, ..	14	11	24·3	..	83	,, ..	23	08	45·7	III
33	,, ..	15	12	16·7	II	84	,, ..	26	20	16·8	IV
34	,, ..	16	04	17·7	..	85	,, ..	27	12	08·9	..
35	,, ..	20	09	50·3	IV	86	,, ..	27	13	03·1	..
36	,, ..	20	09	52·1	II	87	,, ..	28	00	42ca	IV
37	,, ..	20	14	01·2	II	88	,, ..	28	13	14·0	IV
38	,, ..	26	17	53·3	II	89	July ..	1	23	49·0	IV
39	,, ..	27	15	23·8	..	90	,, ..	1	23	54·8	II?
40	,, ..	29	16	43ca	II	91	,, ..	2	02	18·8	II?
41	,, ..	30	09	55·4	..	92	,, ..	2	02	29·0	II?
42	Apr. ..	3	15	59·3	..	93	,, ..	6	03	30·7	..
43	,, ..	8	06	43·5	II	94	,, ..	10	09	53ca	III
44	,, ..	10	17	14ca	I	95	,, ..	11	16	10·4	IV
45	,, ..	11	08	34ca	I	96	,, ..	11	18	53·1	..
46	,, ..	15	19	57·6	..	97	,, ..	14	18	44·9	III
47	,, ..	17	17	47·6	IV	98	,, ..	17	06	28·8	III
48	,, ..	19	03	05·2	I	99	,, ..	20	22	48·3	..
49	,, ..	20	07	29·6	..	100	,, ..	24	19	05·5	..
50	,, ..	21	03	46·6	I	101	,, ..	27	13	53·5	..
51	,, ..	22	14	02·8	IV	102	,, ..	29	09	43·1	III

* G.M.T. (Greenwich Mean Time) is 11 h. 30 m. slow on New Zealand Mean Time (N.Z.M.T.), and 12 h. 00 m. slow on New Zealand Summer Time.

No.	Date and Time (G M T.) *				Maximum Felt Intensity M.-M.)	No	Date and Time (G M T) *				Maximum Felt Intensity (M.-M.).
	1944.	d.	h.	m.			1944.	d.	h.	m.	
103	Aug. ..	6	05	54·9	..	131	Oct. ..	3	15	22·9	.
104	,, ..	8	02	48·5	..	132	,, ..	7	10	12·1	..
105	,, ..	9	05	58ca	II	133	,, ..	9	22	57·3	..
106	,, ..	9	10	31·2	..	134	,, ..	10	10	34·3	..
107	,, ..	13	10	53·7	I	135	,, ..	12	08	10·9	IV
108	,, ..	14	23	42·7	IV	136	,, ..	14	12	17·4	..
109	,, ..	16	20	26ca	V	137	,, ..	23	02	17·9	..
110	,, ..	17	07	24·2	IV	138	,, ..	26	21	29·6	.
111	,, ..	19	15	30·8	..	139	,, ..	27	04	33·0	..
112	,, ..	26	15	42·7	IV	140	,, ..	29	00	40·2	V+
113	,, ..	27	18	33·2	..	141	,, ..	29	04	58·8	.
114	,, ..	30	02	30·7	II	142	Nov. ..	9	14	34·7	
115	,, ..	30	18	28·8	II	143	,, ..	13	00	30·4	.
116	Sept...	2	19	52·8	..	144	,, ..	22	01	45·4	..
117	,, .	3	06	45·5	..	145	,, ..	25	23	14·8	IV
118	,, .	4	12	03·5	..	146	,, ..	27	20	44·1	..
119	,, ..	4	12	54·2	V	147	Dec. ..	5	02	31·7	..
120	,, .	6	02	38·9	IV	148	,, ..	5	14	32·3	II
121	,, ..	7	08	39·9	IV	149	,, ..	7	12	49·9	II
122	,, ..	14	20	01·2	II	150	,, ..	8	11	02ca	I
123	,, ..	23	01	26·6	..	151	,, ..	10	04	58·6	..
124	,, ..	23	18	42·0	III	152	,, ..	12	07	33·2	..
125	,, ..	24	05	43·1	III	153	,, .	13	07	47·9	..
126	,, ..	25	01	00·5	III	154	,, ..	21	23	55·0	..
127	,, ..	27	15	56·1	IV	155	,, ..	24	11	55ca	III
128	,, .	27	16	08·5	II	156	,, ..	26	04	57·6	.
129	,, .	27	21	45·6	III	157	,, ..	26	12	07ca	II
130	Oct. ..	2	07	34·3		158	,, .	30	12	42·3	II

* G.M.T (Greenwich Mean Time) is 11 h. 30 m slow on New Zealand Mean Time (N.Z.M.T), and 12 h 00 m. slow on New Zealand Summer Time.

The following earthquakes tabulated above, are not shown on the map, being beyond its boundary to north-east—Nos 32, 102, 118

THE ESTIMATION OF TOTAL ALKALOIDS IN RYE-GRASS (*LOLIUM PERENNE* L.)

By EUNICE M. CLARE and ISOBEL M. MORICE, Animal Research Division, Department of Agriculture, Wellington

[*Received for publication, 13th March, 1945*]

THE discovery of a number of alkaloids in perennial rye-grass (*Lolium perenne* L.) has been reported by Grimmett and Melville(1), and a method for the estimation of one of these, perloline, was described by Bathurst, Reifer, and Clare(2). As yet the properties of the other alkaloids are not sufficiently well known to allow rapid separation and estimation of them individually. However, in studying the effect of factors such as growth conditions on the alkaloid content of pastures it was found convenient to estimate the total weight of alkaloids present. For this purpose precipitation by Dragendorff's reagent (a concentrated solution of 22·7 g. potassium iodide added to 8 g. bismuth subnitrate dissolved in 20 ml. nitric acid (S.G. 1·18), and filtered), which was found to precipitate all the rye-grass alkaloids which have been isolated, was made the basis of their separation from plant extracts. After further purification the alkaloids were finally weighed as the hydrochlorides. Since the evolution of this method and its application to routine estimations, there has been published by Reifer and Bathurst(3) a paper describing a volumetric micro-method for the estimation of total alkaloids.

PROCEDURE

According to the concentration of the alkaloids, 20 g. to 50 g. of fresh grass or a corresponding amount of dried and finely ground material is taken for analysis. Forty millilitres of 1·5 per cent. (4 ml. concentrated HCl (S.G. 1·18) in 100 ml. water) aqueous hydrochloric acid are added for each five grams of wet pasture, and the extract is boiled for five minutes. This hot solution is then filtered on a Buchner funnel with No. 1 Whatman paper and the residue washed three times with hot aqueous 1·5 per cent. hydrochloric acid. When the combined filtrate and washings are cool, freshly prepared Dragendorff's reagent is added until precipitation is complete. The precipitate, which may be left to settle overnight if desired, is filtered off on a small Buchner funnel. Precipitate and filter paper are transferred to a small beaker and well mixed with 10 ml. of 30 per cent. $Na_2CO_3 \cdot 10H_2O$ solution before adding 100 ml. 90 per cent. alcohol. This solution is filtered on the same Buchner funnel, the precipitate extracted twice more with the same volume of sodium carbonate solution and alcohol and then twice with half quantities. The filtrate is made acid immediately with a few drops of concentrated hydrochloric acid. The alcohol is removed by distillation under reduced pressure, and the concentrate which is now about 50 ml. is cooled and filtered. This is made distinctly alkaline to phenolphthalein with saturated sodium carbonate solution, and shaken in

a separating funnel with 50 ml. portions of chloroform. It has been found that the alkaloids are completely extracted when no further fluorescence of perloline appears in the chloroform. These extracts are centrifuged to break the emulsions. The alkaloids are purified by transferring five times between fresh lots of aqueous acid and chloroform, using very small volumes after the first extraction. Just sufficient hydrochloric acid is added to the aqueous layer to extract the alkaloid from the chloroform, otherwise perloline is lost on drying. The last aqueous extraction of a few millilitres is dried to constant weight in a round bottomed 15 ml. flask under reduced pressure on the water-bath, and the alkaloid present is found by weighing. The amount of perloline present is estimated on aliquots taken before and after drying to check any loss at this stage.

The method was tested by the addition and recovery of small amounts of perloline and nicotine, first in aqueous acid solution, and then in an aqueous acid extract of marram-grass, marram-grass having been found to contain no alkaloids. The following tables give the percentage amount recovered:—

Mixed Solution of Perloline and Nicotine in 1·5 per Cent. Hydrochloric Acid

	Amount added, Mg.	Amount recovered, per Cent.
Perloline hydrochloride . . .	1·5	90
Nicotine hydrochloride . . .	19	88–98

Mixed Solution of Perloline and Nicotine in Extract of 50 g. Marram-grass

	Amount added, Mg.	Amount recovered, per Cent.
Perloline hydrochloride	1·5	72–82
Nicotine hydrochloride	19	82–87

A few typical results from high alkaloid grass at Ruakura and from normal pastures at Wairoa are given below.

	Perloline	*Total Alkaloids*
Ruakura High Alkaloid Rye-grass—	(Mg./100g. dry weight).	
26th March, 1942 .	107, 113	173, 169
9th April, 1942 . .	51, 52	76, 72
14th April, 1942 . .	27, 27	62, 60
23rd April, 1942	58, 59	76, 80
Wairoa Pasture Samples—		
19th March, 1942 . .	8·6, 7·6	23, 24
6th April, 1942	4·3, 4·3	13, 12
13th April, 1942 . .	6·8, 5·6	11, 11
16th April, 1942	6·1, 6·3	25, 27

DISCUSSION

The number and nature of the chloroform soluble alkaloids in rye-grass is still largely unknown and until these are identified and their properties determined, the reliability of the method must be indefinite. Duplicate analyses give satisfactory agreement.

REFERENCES

(1) GRIMMETT and MELVILLE (1943): *N.Z. Jour. Sci. & Tech.*, *24*, 149B.
(2) BATHURST, REIFER, and CLARE (1943): *N.Z. Jour. Sci. & Tech.*, *24*, 161B.
(3) REIFER and BATHURST (1943): *N.Z. Jour. Sci. & Tech.*, *24*, 17B.

STUDIES ON PERLOLINE

PART I. PERLOLINE AND DERIVATIVES: PRELIMINARY STRUCTURAL STUDIES

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Summary

(1) Perloline has a molecular weight of at least 650, contains four methoxy groups and an alcoholic hydroxy group. All four nitrogens are probably tertiary: only two of them are reactive in salt formation.

(2) Many standard methods of investigation—for instance, the customary molecular weight determinations—were inapplicable to perloline and its derivatives.

(3) Several salts and simple derivatives of perloline were prepared and their chemical formulæ established.

(4) Chemical analysis of these derivatives confirmed the original formula of perloline, $C_{40}H_{34}O_7N_4$.

(5) Other derivatives were prepared and purified. Their structure still remains uncertain.

(6) Many oxidation products were obtained without achieving extensive degradation.

(7) Perloline can be readily converted into unusual water-insoluble compounds of non-basic nature. Some of them are reconvertable into perloline.

IN the course of investigations on facial eczema during the years 1939-41 a new alkaloid was found to be present in *Lolium perenne*. Methods of extraction, isolation, and estimation of this alkaloid named perloline were described elsewhere in this *Journal* (1, 2, 3, 4, 5).

From the very beginning, perloline proved to be an alkaloid of rather unusual properties. It was decided by the Chemical Laboratory, Department of Agriculture, and the Plant Chemistry Laboratory, Department of Scientific and Industrial Research, to make a joint investigation of perloline in further detail. At this juncture we wish to thank the Heads of the two Departments for granting us the opportunity of collaboration on this work.

Various salts and derivatives of perloline were prepared with a view to gaining more information about the alkaloid, and if possible to establish the constitution of perloline. Due mainly to wartime conditions, which diverted our activities into other channels, the ultimate objective was not achieved. Furthermore, in the course of work we found that perloline presented unexpected difficulties, such as irregularities in the molecular weight estimations. A thorough investigation of perloline would necessitate the isolation and purification of fairly large quantities of the alkaloid. All perloline at our disposal did not amount to more than 30 g. However incomplete our findings may be, we feel that the information obtained so far fully justifies a preliminary report.

About eighty-five species representing forty genera of the *Gramineae* growing in New Zealand, and ten species of the *Cyperaceae* and an equal number of the *Juncaceae*, were examined for perloline. In most cases several samples were examined, and in general stems, leaves, and heads

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have been examined separately. Perloline has been found in readily detectable concentration only in *Lolium perenne* L., *L. temulentum* L. (grown both from endophyte-infected and endophyte-free seed), *Festuca arundinacea* Schreb., *Setaria lutescens* (Weigel.) F. T. Hubb, and in traces in *Lolium multiflorum* Lam. Seventy-five other species* gave no evidence for perloline, with doubtful traces in a few cases.

At about flowering time in *Lolium temulentum* and *Setaria lutescens* most of the perloline was in the stems (65–120 mg. per cent.), with less in leaves (a trace to 30 mg. per cent.) and heads (19–28 mg. per cent.). Traces were found in roots, and no alkaloid in the seed. One sample of *Setaria* total tops weighing 570 g. gave about 240 mg. of perloline hydrochloride.

Analysis of the hydrochloride was reported previously(3) showing a formula $C_{40}H_{34}O_7N_4$. The base contained four methoxy groups and formed a hydrochloride with two equivalents of acid. The hydrochloride was yellow, and when "air-dry" or dried in a vacuum desiccator contained about seven molecules of water and gave no constant melting-point. It became anhydrous under high vacuum. The yellow base, m.p. 181°, was prepared by ammonia diffusion, and after drying in a vacuum the formula was $C_{40}H_{34}O_7N_4 . H_2O$. Intense drying under high vacuum or heating at 160° has shown no loss of water. The base was recrystallized from alcohol-ether giving prisms, m.p. 253°, which contained a molecule of alcohol of crystallization. Support for the formula $C_{40}H_{34}O_7N_4$ was given by analysis of salts, the dipicrate m.p. 243°, the diperchlorate m.p. 282°, and the dihydriodide of the di-N-methyl base, m.p. 261°. Most of the other materials derived from perloline gave analytical values which could not be reproduced exactly. Many materials—*e.g.*, perloline base, methylperloline, and demethylated perloline base—were hygroscopic and on drying in a vacuum desiccator or under high vacuum lost some moisture, but analysis gave values which were appreciably lower than expected, due apparently to retention of one molecule of water. Many materials gave difficulty in the Dumas nitrogen determination, often encountered in alkaloids, and were hard to burn in carbon-hydrogen determinations.

* *Agrostis alba* L., *A. semiverticillata* (Forsk.) Christens, *A. stolonifera* L., *Agropyron repens* (L.) Beauv., *A. scabrum* Beauv., *Aira caryophyllea* L., *A. praecox* L., *Alopecurus pratensis* L., *Ammophila arenaria* (L.) Link, *Anthoxanthum odoratum* L., *Arrhenatherum elatius* (L.) Mert. et Koch., *Arundinaria* sp., *Arundo conspicua* Forst., *A. fulvida* Buch., *Avena fatua* L., *Briza maxima* L., *B. minor* L., *Bromus carinatus* Hook. et Arn., *B. catharticus* Vahl., *B. gussonii* Parl., *B. mollis* L., *Cortaderia dioeca* (Sprengel.) Speg., *Cynodon dactylon* (L.) Pers., *Cynosurus cristatus* L., *C. echinatus* L., *Dactylis glomerata* L., *Danthonia cunninghamii* Hook., *D. flavescens* Hook. f., *D. pilosa* R.Br., *D. raoulii* Steud., *D. semiannularis* R.Br., *Dichelachne crinita* Hook. f., *D. sciurea* Hook f., *Deyeuxia arenoides* Buch., *D. forsteri* Kunth., *Digitaria sanguinalis* (L.) Scop., *Echinochloe colona* (L.) Link, *E. crus-galli* (L.) Beauv., *Festuca multinodis* Petrie and Hack., *F. novae-zelandiae* (Hack.) Cockayne, *F. rubra* L. and var. *commutata* Gaud., *Glyceria fluitans* (L.) R.Br., *Hierochloe redolens* R.Br., *Holchus lanatus* L., *Hordeum murinum* L., *H. vulgare* L., *Lagurus ovatus* L., *Microlaena avenacea* Hook. f., *M. stipoides* R.Br., *Miscanthus nepalensis* Hack., *M. sinensis* Anders., *Nassella trichotoma* (Nees) Hack., *Oplismenus undulatifolius* Beauv., *Oryzopsis miliacea* (L.) Benth. and Hook. f., *Panicum capillare* L., *P. miliaceum* L., *Paspalum dilatatum* Poir., *P. distichum* L., *Phalaris canariensis* L., *P. minor* L., *P. tuberosa* L., *Phleum pratense* L., *Polypogon monspeliensis* (L.) Desf., *Poa anceps* Forst., *P. annua* L., *P. caespitosa* Forst., *P. pratensis* L., *P. trivialis* L., *Setaria verticillata* (L.) Beauv., *Sporobolus capensis* Kunth., *Stenotaphrum secundatum* (Walt.) Kuntze, *Stipa arundinacea* Benth., *S. teretifolia* Steud., *S. variabilis* Hughes, *Trisetum youngii* Hook. f. *Vulpia megalura* (Nutt.) Rydb. · of the *Cyperaceae*—*Carex dissita* Sol. ex. Hook. f., *C. pumila* Thunb., *Cladium sinclairii* Hook. f., *Cyperus eragrostis* Lam., *C. rotundus* L., *Scirpus cernuus* Vahl., *S. prolifer* Rottb., *Uncinia riparia* R.Br., *U. uncinata* (Linn. f.) Kukenth.; of the *Juncaceae*—*Juncus bufonius* L., *J. lampocarpus* Ehr., *J. macer* Grey, *J. pallidus* R.Br., *Luzula campestris* DC.

Molecular weight determinations gave little information. By titration the minimum molecular weight of perloline was fixed at about 300. The isothermic method of Niederl was the only one giving definite information, and this fixed the minimum molecular weight as 650, corresponding to $C_{40}H_{34}O_7N_4$. The Rast method was inapplicable, due to lack of solubility of most materials in camphor and allied solvents and obvious decompositions. Methylperloline gave a constant value of about 240. In phenol, values for several materials were 170 to 250, apparently anomalous. The Bobransky method was also indefinite. Further evidence fixing the minimum molecular weight at the 650 level was provided by monoacetylperloline, whose acetyl content showed one acetyl group for a molecular weight of the base of 650. The minimum molecular weight of 650, and the presence of all four nitrogens in unsaturated ring systems, place perloline among the most complicated alkaloids so far reported.

Of the seven oxygen atoms of perloline, four are accounted for as methoxy groups. Perloline can be demethylated to a phenolic base, not melting at 350°, and containing no methoxy groups. This body is a typical alkaloid. There is no ester or lactone grouping, and perloline is stable to hydrolytic agents, except alcoholic potash, with which it gives a condensation product, without liberation of acid. The formation of a monoacetyl derivative is taken to show the presence of an alcoholic hydroxy group in perloline. Perloline has no phenolic properties. The acetyl derivative is formed with elimination of a further water molecule, and is a colourless material, m.p. 296 300°, showing in solvents a dull blue fluorescence, and having no basic properties. Hydrolysis gave perloline. Demethylated perloline on acetylation gave a penta-acetyl derivative, and di-N-methylperloline still gave a monoacetyl derivative. These facts, together with the ease of hydrolysis of acetyl perloline, are taken to show that acetylperloline is an O-acetyl derivative.

The thionyl chloride material contains chlorine and may be a chloro derivative. There are no ketonic reactions and no methylenedioxy group; the two remaining oxygen atoms are ether or inert carbonyl groups and may account for the lack of basicity of the two nitrogen atoms.

Two nitrogen atoms of perloline are basic and form salts, the other two are inert. Perloline is stable to nitrite and acid in the cold, and is not N-methylated by formaldehyde and formic acid; primary and most types of secondary amino groups are therefore absent. There is no N-methyl group. With methyl iodide perloline forms di-N-methylperloline dihydriodide, m.p. 264°. This material with alkali gives di-N-methylperloline base, m.p. 199°, a cream-coloured compound of typical alkaloidal properties forming yellow salts. The same base results from methylation of perloline by methyl sulphate and alkali. The presence of two —NH groups in perloline is unlikely, as these would have to be stable to acetic anhydride, N-methylation, and nitrite. It appears that two tertiary (pyridinic) nitrogens are methylated, as happens with harmine, and that di-N-methylperloline is a tertiary base. It could not be further methylated readily, but was stable to alkali, and did not have properties of a quaternary base. With methyl sulphate on refluxing it apparently gave quaternary material. Methylperloline was acetylated, and the material resulting on hydrolysis formed a new weak base which was similar in properties to one of the "B" alkaloids(2).

A number of unusual materials was prepared from perloline, but the interpretation is as yet not clear, mainly through inadequate analytical data. Alcoholic potash or soda and formaldehyde and alkali formed yellow

non-alkaloidal and feebly fluorescent bodies, m.p. about 200–230°, extractable by chloroform from acid or alkaline suspension. Possible formulæ were $C_{40}H_{37}O_{10}N_4$ and $C_{40}H_{40}O_9N_4$ respectively, showing no addition of carbon to perloline. These bodies were stable to alkali, but with acid reverted to perloline, and on very mild oxidation, gave perloline. Neither material would acetylate, and on oxidation according to the Kuhn-Roth procedure no volatile acid was formed.

Perloline could not be reduced by any means tried, including catalytic hydrogenation. Oxidation proceeded easily and gave rise to a variety of products all of which contained nitrogen. No non-nitrogen body or simple acidic material was isolated. Alkaline peroxide formed a white non-alkaloidal material, m.p. 290° (dec.), retaining four nitrogen and four methoxy groups, formula $C_{38}H_{36}O_9N_4$. Acetone permanganate oxidation of perloline formed a colourless non-basic material $C_{31}H_{28}O_7N_4$, m.p. 290°, retaining the methoxy and nitrogen groups of perloline. Acetone permanganate oxidation of demethylated perloline formed an acidic body, "perlololic acid," containing no methoxy groups. The most interesting product of oxidation of perloline is alkaloid "C," now named perlolidine. This base was isolated from rye-grass extracts by Grimmett and Waters(2), and material derived from perloline by oxidation has been found identical with their product.

Perloline itself, the demethylated and methylated bases and other products, also perlolidine, gave no reactions of an indole nucleus with a free α or β position *e.g.*, with *p*-dimethylaminobenzaldehyde and other indole reagents. The vapours given off during some oxidations, and a fraction of the simple nitrogen bodies resulting from alkali degradation of perloline, gave strong indole reactions and odours. Most of the materials gave pink colours with *p*-dimethylaminobenzaldehyde, others tended to purple colours. Pink colours result from indoles having a free α position, crimson-purple colours from free β position materials(6, 7). Small yields of varnish-like highly odoriferous materials giving indole reactions were extractable from products of alkali degradation, by ether from acid solution. Alkali degradation also gave an appreciable basic fraction, part of which was isolated as a picrate, m.p. 199°, the base from which had an odour of quinoline. This picrate was not identified with that of quinoline or some methyl quinolines. Other amine- or piperidine-like material also resulted from alkali-degradation.

EXPERIMENTAL

Perloline and its Simple Salts

Perloline Base.—The recrystallized hydrochloride was dissolved in very dilute hydrochloric acid, and the warm solution was treated with ammonia gas under a bell-jar (ammonia diffusion). Light-yellow needles separated, and after two such ammonia diffusions the base was dried in a vacuum desiccator, m.p. 181°, with reddening from 165°. Base of this m.p. was repeatedly prepared in this way from various samples and also by sodium carbonate precipitation. From hot solutions a darker base separated, also of m.p. 181°. Analytical data gave—

——	Found.	Theoretical for $C_{40}H_{34}O_7N_4$, H_2O.
C	68·4, 68·3, 68·7, 68·4	68·37
H	5·20, 5·20, 5·16, 5·22, 5·14, 5·23	5·15
N	7·98, 8·18	7·98
$(OCH_3)_4$ ..	17·8, 17·8	18·0
$CH_3(N)$ ..	Nil	..

There was no water loss on heating to 70° in high vacuum for several hours. The base heated at 160° for five hours went red and dark yellow on cooling, m.p. 180°, and gave C = 69·06, H = 4·78. Some of the above base was dissolved in hot alcohol, concentrated, excess ether added, and the precipitated shining prisms were dried. These had a m.p. 252° with blackening from 245°. Analytical data gave

—	Found.	Theoretical for $C_{40}H_{34}O_7N_4$, C_2H_5OH.
C	68·93, 69·10	69·23
H	6·30, 5·66	5·50

Molecular distillation of the base led to considerable decomposition, but some distilled over unchanged. Perloline base is almost insoluble in water, ether, isoamylether, anisole, and dioxane, soluble to about 1 per cent. in alcohol, chloroform, pyridine, less in acetone, still less in cyclohexanol. The solutions are yellow with green fluorescence. Colour and fluorescence vary in intensity in the various solvents. It is readily soluble in phenol. The chloroform solution is unstable in bright sunlight, loses its fluorescence quickly, and decomposes, forming yellow non-basic material.

The molecular weight in phenol gave a value 170, and perloline was recovered from the solution. Urethane could not be used as a solvent, as combination took place. The Rast method was inapplicable, due to rapid decomposition at the high temperature The isothermic method of Niederl and Niederl(10) was used employing a nearly saturated solution of perloline in chloroform (c = 35·1 mg. in 4·9 ml. of solution). This solution showed least change with a solution of azobenzene in chloroform at 0·01M, which is rather dilute for accurate measurements, but nevertheless fixed the molecular weight of perloline at a minimum of 650-700. The Bobransky method in alcohol or chloroform failed to give definite results, due to the sparing solubility of perloline and the slow rate of solution. Perloline was dissolved in a known volume of standard acid, an equal volume of acetone added, then cochineal indicator, and the solution titrated with alkali to a definite end-point. The equivalent was 280-350. Active hydrogen determinations failed through insufficient solubility of perloline in anisole.

Perloline Dihydrochloride.—Perloline was isolated from grass in this form and was repeatedly recrystallized from water, in which it is moderately soluble. The pure material was pale yellow when air-dry, but when contaminated with even small traces of tarry material retained a red colour. The red forms (constituting most of the so-called " B " fractions of Grimmett and Waters(2)) when purified gave yellow perloline hydrochloride. The pure pale-yellow salt was obtained by washing the red crystals with small quantities of absolute alcohol. The air-dry hydrochloride contained 13-15 per cent. of moisture, theoretical for $C_{40}H_{34}O_7N_4$, 2HCl, $7H_2O$ is 14·3. The moisture was not lost in a vacuum desiccator, but was removed on drying in high vacuum. At an intermediate stage of drying a red colour appeared, but the anhydrous material was yellow. Analysis of dry hydrochloride is reported previously(3). The melting-point of many samples of air-dry material was in the range 220-265°. These samples also showed considerable variations of solubility in alcohol and acetone, but all fractions were perloline hydrochloride. Further analytical data gave N (micro Kjeldahl) = 7·51, 7·34, and methoxy 16·2. The aqueous solution was optically inactive (c = 0·93 in water).

Perloline Dipicrate.—The neutral or slightly acid solution of the hydrochloride with excess saturated aqueous picric acid deposited an amorphous precipitate. Using pure perloline hydrochloride, small clusters of tiny needles were soon formed. Recrystallization from acetone-water gave yellow needles, m.p. 242°. This picrate was also prepared from several red forms of perloline hydrochloride, from the total alkaloid of *Setaria lutescens* and *Festuca arundinacea* as yellow or reddish needles, m.p. 242°, showing no depression on admixture with authentic picrate. Analytical data gave—

—	Found.	Calculated for $C_{40}H_{34}O_7N_4$, $(C_6H_3O_7N_3)_2$.
C	56·7	54·8
H	3·35	3·49
N	12·24, 12·68	12·25
$(OCH_3)_4$	11·3	10·92

Perloline Diperchlorate.—Comparatively concentrated solutions of the hydrochloride and excess perchloric acid gave characteristic spheroids of needles. Recrystallization from acetone-water on concentration gave yellow needles, m.p. 284° (dec.), with slight sintering from 235°. From solutions containing much acid or from impure red forms of the hydrochloride, a persistently red form of the perchlorate formed, recrystallized as red needles, m.p. 284°, showing no depression on admixture with the yellow form, but often further sintering before melting. Analytical data gave

—	Found.	Theoretical for $C_{40}H_{34}O_7N_4(HClO_4)_2$.
C	53·9	54·2
H	4·12, 4·12	4·06
N	6·36, 6·29	6·35
$(OCH_3)_4$	14·6	14·04

Perloline Mercurichlorides. Neutral solutions of perloline with excess mercuric chloride gave yellow crystals, recrystallized from hot water in which they are sparingly soluble, m.p. 265°. From acid solutions the precipitate was orange-red and was recrystallized easily from hot water, m.p. 201°, 199°.

Perloline Reineckate.—Aqueous solutions of perloline hydrochloride and ammonium reineckate deposited reddish crystals; recrystallization from acetone-water gave yellow stubby prisms, decomposed at 195–205° without melting at 275°.

Microchemical Slide Reactions of Perloline.—Perloline gave highly insoluble precipitates with most alkaloid reagents; precipitates are mostly amorphous on the slide and only a few crystallize readily. Precipitates with potassium bismuth iodide, potassium mercuric iodide, potassium tri-iodide, gold chloride and bromide, and platinum chloride did not crystallize. The precipitates with bismuth iodide separated from a 1 : 10,000 solution of perloline on standing overnight. The picrate separating first formed large clusters of fine needles, perchloric acid in reasonably concentrated solutions gave large spheroids of fine needles, gradually developing into large needle clusters. Potassium cadmium iodide slowly formed rod and

blade clusters. The bromo salts formed as described by White(11, 12) are characteristic and useful for recognition of perloline in reasonably concentrated solutions. The cadmium and mercury bromosalts are similar, first appearing as small spheroids, developing to large hexagonal rods or plates, mostly isolated, and often paired. The bromosalts with bismuth, lead, and antimony form large clusters of fine needles.

Adsorption of Perloline

Perloline is very easily adsorbed by charcoal, but no way was found of recovering it. The neutral solution is adsorbed on the fibre of grass, and washed off by dilute acid. Thus in the extraction of alkaloid from wet grass by juice-extraction procedures the majority of the alkaloid remains on the fibre. Miss I. M. Morice (Chemical Laboratory, Department of Agriculture) reported that perloline in alcohol is not very strongly adsorbed on activated alumina, slightly on calcium hydroxide, and not at all on calcium carbonate and sugar.

Structural Evidence on Perloline

The methylenedioxy reaction described by Gadamer(13) was negative, using cotarnine as a standard. Perloline is insoluble in carbonate and sodium hydroxide solutions, gives no Millon reaction, and is unaltered by lead tetra-acetate in acetic acid (absence of glycol groups). It is stable to continued standing with concentrated hydrochloric acid, but after long refluxing with acid some demethylation took place. Cold 50 per cent. sulphuric acid was without action, as was also prolonged standing with concentrated sodium hydroxide. Refluxing with 30 per cent. sulphuric acid in the Kuhn-Roth apparatus gave no volatile acid. Sodium nitrite and dilute hydrochloric acid was without action in the cold. The typical indole nucleus reactions with *p*-dimethylaminobenzaldehyde, vanillin, and the Hopkins-Cole reaction were negative. 2, 4-dinitrophenylhydrazine in dilute hydrochloric acid and semicarbazine in neutral solution gave no precipitates.

Acetylation of Perloline. Perloline base was refluxed gently for five hours with excess of acetic anhydride, forming a red solution. Most of the anhydride was boiled off, then water added, and the solution boiled. A whitish-brown product separated and was filtered off, leaving a yellow solution with green fluorescence, not due to perloline. The solid was extracted with hot chloroform, the solvent partly boiled off, and acetone added, when a creamy-yellow solid separated leaving a yellow solution. Acetone washings removed further colour. 197 mg. of perloline gave 116 mg. of needles at this stage, blackening at 265-270° without melting. Further recrystallization from chloroform-acetone gave cream needles, m.p. 296-300° (dec.), with sintering from 280°. 142 mg. of perloline base gave 70 mg. of pure acetyl derivative. Analytical data gave —

—	Found.	Theoretical for $C_{40}H_{33}O_7N_4(OCCH_3)$.	Theoretical for $C_{40}H_{33}O_7N_4(OCCH_3) - H_2O$.
C	70·3, 70·3, 70·4 ..	69·61	71·24
H	4·81, 4·74 ..	4·96	4·81
N	7·97, 8·01 ..	7·70	7·92
$(OCH_3)_4$ ..	16·5, 15·8 ..	17·1	17·5
*$(OCCH_3)$ ..	6·2, 5·6, 7·3, 7·2 ..	5·8	6·1

* Acetyl by refluxing 10-13 mg. of material with 30 per cent. sulphuric acid for three hours in the Kuhn-Roth apparatus, acetic acid determined by the Friedrich-Rapoport method.

Acetyl perloline is almost insoluble in water, ether, very slightly in acetone, alcohol, more readily in chloroform. It is readily extracted from acid or alkaline suspension by chloroform, the solution being colourless with a dull blue fluorescence. There were no typical alkaloidal properties. On refluxing for a short time with dilute sulphuric acid perloline was formed in quantity. Lead tetra-acetate in acetic acid was without action. The material gave a strong red Millon reaction.

Demethylation of Perloline.—Fifty per cent. sulphuric acid has been used to demethylate some alkaloids—for example harmine to harmol(8, 9). 419 mg. of perloline hydrochloride was refluxed five hours with 12 ml. of 50 per cent. (by volume) sulphuric acid, after which time only a trace of perloline remained. During the action there was a strong odour of phenol. The solution was diluted, any traces of tarry material filtered off, the solution concentrated and neutralized with sodium carbonate. The yellow solution became dark red-brown and a dark precipitate separated. This was washed with water and weighed 229 mg. Similarly, 310 mg. of perloline hydrochloride gave 120 mg. of base. The base was dissolved in very dilute hydrochloric acid and precipitated by several ammonia diffusions, finally washing with a little alcohol to remove any traces of perloline. The purified base was finely crystalline, dark brown in colour, and showed red streaks on scratching. In another preparation 523 mg. of perloline hydrochloride gave 309 mg. of demethylated base using ammonia for precipitation and diffusion. The pure preparations did not melt at 350°. Analytical data gave—

—	Found.	Theoretical for $C_{36}H_{22}O_3N_4(OH)_4, H_2O$.
C	66·8, 66·8, 67·65*, 67·34*	67·08
H	4·07, 4·18, 4·42, 4·29*, 4·20*	4·22
N†	8·76, 8·70, 8·98, 8·94, 8·88, 8·72	8·69
$(OCH_3)_4$ ..	Nil	Nil
$CH_3(N)$ ..	Nil	Nil

* Intensely dried over P_2O_5 in high v acuum. † Determinations by the micro Kjeldahl gave low values, for base 7·8, 6·5, and hydroch loride 4·1.

Demethylated perloline is slightly soluble in boiling alcohol, water, acetone, and chloroform to solutions of faint-yellow colour with a trace of faint-green fluorescence. It is insoluble in ether, and not extractable from any alkaline solutions by solvents. In dilute sodium hydroxide it is readily soluble to form a dark-red solution; it is not soluble in ammonia or carbonate. It dissolves readily in acids forming yellow non-fluorescent solutions of the salts. An orange hydrochloride recrystallized from alcohol melted at 210° and an amorphous picrate at 206°. The base when subjected to molecular distillation at 0·01 mm. was visibly decomposed at a high temperature, and from the white sublimate (with much dark carbonized material) a small amount of perlolidine was isolated. The microchemical reactions of demethylated perloline are similar to those of perloline. Crystalline precipitates were obtained with potassium cadmium iodide, the bromo salts, and less-distinct crystals with gold chloride, bromide, and perchloric acid.

Demethylated perloline did not give a Millon reaction or any colour with ferric chloride. 21·1 mg. of perloline was demethylated in the Kuhn-Roth apparatus and the solution distilled. No volatile acid was formed. A solution of the base in concentrated sodium hydroxide formed perlolidine slowly in the cold, rapidly on warming. A few milligrams of base were

refluxed with normal methanolic potash; the red solution on acidification developed a strong blue fluorescence, and from this solution a small amount of perlolidine was isolated and identified by several microchemical reactions. 100 mg. of the base was dissolved in alcoholic potash and refluxed for two hours, water added, and the alcohol boiled off. About 14 mg. of demethylated body insoluble in acid was filtered off, and from the solution 14 mg. of perlolidine base, m.p. 323°, was isolated.

Acetylation of Demethylated Perloline.—113 mg. of demethylated perloline was refluxed with excess acetic anhydride for three hours. A blue-green fluorescence appeared. Most of the anhydride was boiled off, and the remaining anhydride decomposed by adding water and boiling. The brown precipitate was filtered off, some specks of tar removed, and the precipitate suspended in dilute acid and extracted with chloroform. The extract was faint yellow with a blue fluorescence. On concentration a slightly discoloured precipitate formed, and was washed with acetone. Yield, 68 mg. of light yellow needles, m.p. 216° (dec.). Analytical data gave—

	Found.	Theoretical for $C_{36}H_{22}O_{2}N_{4}(OCCH_3)_5$.
$(OCCH_3)$	24·4, 24·3	25·6

The solution after hydrolysis was apparently demethylated perloline. Penta-acetyl-demethylated perloline is insoluble in water, soluble in chloroform to a solution of faint-yellow colour and blue fluorescence. It is soluble in carbonate solutions.

Oxidation of Demethylated Perloline.—23·8 mg. of demethylated perloline was suspended in 50 ml. of water, sodium carbonate and permanganate added until a faint pink colour remained. An indole-like odour was detectable, but no crystalline precipitate formed. The solution was concentrated, acidified, and distilled in the Kuhn-Roth apparatus. About 0·4 molecular proportions of acid were formed, and the residual solution gave a trace of perlolidine.

Demethylated perloline was oxidized in hot dilute sodium hydroxide solution with permanganate until a faint pink colour remained. The aqueous solution was acidified, made alkaline with carbonate, and extracted with chloroform. From this solution a concentrate was obtained which gave complete agreement with the properties and the microchemical reactions of perlolidine.

241 mg. of demethylated perloline base was dissolved in 30 ml. of water containing a drop of dilute sulphuric acid, carbonate added to slight alkalinity, then permanganate added to the hot solution until a definite pink colour remained. The solution was acidified with dilute sulphuric acid, and sodium sulphite added to the hot solution until all the manganese dioxide had dissolved. The solution was filtered and concentrated. On standing overnight the solution deposited slightly discoloured crystals, which were filtered off and washed with a little water; yield, 40 mg., m.p. 268–271°. This material was extracted with hot alcohol, leaving a trace of tarry material, and alcohol almost removed. Water was added, the solution clarified with norite, and the concentrated solution left standing overnight. 19 mg. of colourless needles formed, m.p. 279–281°. The mother liquor gave a few more milligrams of the same material. The mother liquor from the initial separation gave on extraction only a trace of tarry material. Analytical data gave—

$C = 54{\cdot}90$, $H = 4{\cdot}47$, $N = 19{\cdot}58$; (OCH_3) and $CH_3(N)$, Nil.

This material was insoluble in water and dilute acids, sparingly soluble in hot alcohol or chloroform, and soluble in dilute alkali.

Oxidation of Demethylated Perloline by Lead Tetra-acetate.—A few milligrams of base were dissolved in glacial acetic acid and stood overnight with excess lead tetra-acetate. The red solution when diluted showed a strong blue fluorescence. Perlolidine was isolated from this and identified by microchemical reactions. 108 mg. of base was dissolved in acetic acid, and excess lead tetra-acetate added and the mixture shaken. After a few hours much perlolidine appeared and increased in concentration for about twenty-four hours. Then the fluorescence began to disappear, and after about four days only a trace of perlolidine remained. No other alkaloidal body appeared to be formed.

The Action of Methyl Iodide on Perloline.—Perloline base was suspended in excess acetone (usually not sufficient for complete solution), excess methyl iodide added, and the solution allowed to stand for a day with intermittent shaking. All the perloline dissolved, and the solution lost all its green fluorescence, assuming a red colour. Evaporation of the solvent gave a yellow residue, which was washed with a little acetone to remove a trace of resinous material. The residue was yellow, separate preparations melting at 261°, 259°, and 259°. It was recrystallized from hot acetone, in which it is soluble to less than ½ per cent., forming a red solution, giving on considerable concentration yellow needles, m.p. 264°. Analytical data gave—

——	Found	Theoretical for $C_{40}H_{32}O_7N_4(CH_3)_2(HI)_2$.
C	52·15, 51·84, 51·92	52·16
H	4·25, 4·19, 4·47	4·14
N	5·80, 5·81	5·80
$(OCH_3)_4$ ..	11·9, 12·4	12·83
$CH_3(N)$ ..	2·65	3·10

The hydriodide was readily soluble in water, giving a yellow solution without fluorescence. The aqueous solution was treated with sodium hydroxide, when a pale-yellow gelatinous precipitate formed. This was extracted with chloroform, the chloroform extract shaken with dilute acid, and the acid solution ammonia diffused. The cream-coloured precipitate of fine needles was dried, washed with a little acetone, which left a faint-cream material, m.p. 199 201°, showing no depression on admixture with di-N-methylperloline of m.p. 200°, prepared by the methyl sulphate-alkali method.

Methylation of Perloline.—Perloline base was refluxed with excess formaldehyde and formic acid for several hours, but only perloline was recovered. Perloline hydrochloride in about 1 per cent. aqueous solution was treated with a few drops of concentrated sodium hydroxide, then excess methyl sulphate added in small fractions with frequent shaking. The solution was made alkaline when required.

After about half an hour the yellow colour of perloline faded and a precipitate of cream needles separated. These were filtered off, washed with water, and recrystallized by ammonia diffusions from faintly acid solutions. The base was washed with a little acetone each time to remove a trace of yellow material which developed during manipulation. 552 mg. of perloline hydrochloride in 100 ml. of water gave 244 mg. of methylperloline base after two ammonia diffusions. This melted at 199°, as for other preparations,

and was not altered in m.p. on further purification by diffusion. Analytical data gave—

—	Found.	Theoretical for $C_{40}H_{32}O_7N_4(CH_3)_2$, H_2O.
C	68·31, 68·51	69·23
H	5·59, 5·20	5·49
N	7·84, 7·80	7·69
$(OCH_3)_4$	17·4, 18·1	17·03
$(CH_3(N))_2$	3·8	4·12

Methylperloline base is slightly soluble in water, more so in acetone and ether, readily in alcohol chloroform, and is easily extracted from alkaline solutions by solvents. Solutions of the base in chloroform have a faint-yellow colour with little, if any, fluorescence. Solutions tend to darken during manipulation to form some of the yellow material mentioned above. In the molecular weight by the Rast method no apparent decomposition or combination was evident and values 247–249 and 246–248 were given. The Bobransky method gave indefinite values as with perloline, although methylperloline is fairly soluble in the solvents. In the active hydrogen determination with anisole as solvent (1·5 ml.) the base was just sufficiently soluble (10 mg.). 10·9 mg. (9·9 mg.) of base gave 0·43 ml. (0·33 ml.) of methane at 20°, calculated for one active H, and a molecular weight of 700 is 0·36 ml. (0·32 ml.) at 0°. The residual material was yellow and extractable from acid solution by chloroform.

In distinction to the base, the salts of methylperloline are strongly yellow coloured (like perloline salts), but without fluorescence. A small amount of hydrochloride recrystallized from alcohol-acetone formed yellow needles, m.p. 268-270° (dec.). The microchemical slide reactions were similar to those of perloline, largely amorphous, and very insoluble. The perchlorate crystallized readily and was distinct from that of perloline.

A dilute solution was made just alkaline and heated with permanganate until a faint pink colour remained. From the solution perlolidine was extracted in small yield and identified by many microchemical reactions. 105 mg. of the base was oxidized as above with excess permanganate, the manganese dioxide dissolved by passing in sulphur dioxide, and the solution concentrated. A white crystalline material formed, yield 7·6 mg., m.p. 200–210°. Methylperloline base was refluxed with excess aqueous or alcoholic potash, but only methylperloline was recovered; 100 mg. of the base was refluxed for long periods with excess methyl iodide in acetone, methanol, or ethanol, but in each case only methylperloline base was recovered. Methylperloline base was refluxed for half an hour with excess methyl sulphate, water added, and the solution warmed. It contained yellow material not extractable by chloroform from acid or alkaline solutions. A dilute solution treated with a few drops of formaldehyde made just alkaline and warmed gave yellow-green needles.

Acetylation of Methylperloline.—147 mg. of methylperloline was refluxed with excess acetic anhydride for three hours, when the solution became dark and strongly green fluorescent. Water was added and the solution warmed, when a dark precipitate formed with tarry material. Some tar was removed mechanically. Hydrochloric acid was added and the solution extracted with chloroform. The chloroform extract was then shaken into dilute carbonate, when most of the yellow material went into the aqueous layer.

The alkaline solution was made just acid and again extracted with chloroform. The residue after removal of solvent contained some tar. It was dissolved in glacial acetic acid, and thrown out by water as yellow plates, m.p. 180–185°, yield 22 mg. 110 mg. of methylperloline similarly treated gave 17 mg. of needles, m.p. 219–221° (dec.). Analytical data on the two preparations gave—

——	Found.	Theoretical for $C_{40}H_{31}O_7N_4(CH_3)_2(OCCH_3)$.
(CH_3CO) ..	8·0, 7·6	5·8
$(OCH_3)_4$ ..	16·9..	16·6

Acetyl methylperloline is soluble in chloroform, giving a yellow solution with no fluorescence. It can be shaken from chloroform into alkali. It is insoluble in water.

The solution remaining after hydrolysis by dilute sulphuric acid was yellow. When this was shaken with chloroform a pink colour with strong yellow fluorescence was extracted slowly. The same material was extracted readily when the solution was made alkaline. 297 mg. of methylperloline was treated similarly, but only a trace of the acetyl material was obtained. The chloroform extract was shaken with alkali, but little dissolved in the watery layer. The non-extractable fraction and the original acid solution were mixed and made alkaline, when much of the pink material was extracted. A few milligrams of yellow hydrochloride of this base were obtained. The material proved to be an alkaloid. Acid solutions gave strong alkaloid reactions. The yellow hydrochloride is soluble in water. The alkaloid was extracted readily from alkaline solutions by chloroform, giving a pink colour with yellow fluorescence. Dilute acid solutions were sufficiently hydrolyzed to allow the free base to be extracted appreciably on shaking with chloroform. The chloroform solution showed an absorption maximum at 535 mμ.

Demethylation of Methylperloline.—200 mg. of methylperloline was refluxed with 4 ml. of 50 per cent. sulphuric acid for three hours. The yellow solution was made alkaline with carbonate, giving a dark precipitate with a red supernatant solution. The precipitate weighed 132 mg., m.p. 286°. It was purified by dissolving in acid, washing with chloroform to remove some tarry material, and then by ammonia diffusion. The black amorphous precipitate was washed with alcohol, and weighed 38 mg., not melting at 330°. It was similar to demethylated perloline in properties. Analytical data gave—

——	Found.	Theoretical for $C_{36}H_{18}O_3N_6(OH)_4(CH_3)_2$.
$(CH_3(N))_2$ ..	4·2	4·6
N	5·7	8·6

On standing in sodium hydroxide solution, this material gave some perlolidine.

The Action of Alcoholic Potash on Perloline.—227 mg. of perloline hydrochloride were refluxed for three hours with 5 ml. of 0·5 N alcoholic potash. On dilution a precipitate formed, and on making acid a light-yellow flocculent precipitate appeared. This was washed with water,

dissolved in chloroform-acetone, concentrated, and precipitated out by addition of water. The product was yellow and contained traces of tar. The yield was 186 mg., m.p. 199–206°. A portion of this material was dissolved in chloroform and shaken with alkali, chloroform almost boiled off, taken up in acetone, and thrown out with water. The yellow precipitate melted at 203°.

Another preparation extracted from alkaline suspension by chloroform gave a m.p. 214°. Recrystallization from chloroform-acetone gave small yellow crystal clusters, m.p. 223°, with blackening from 206°. The various preparations showed no mixed melting-point depressions. Analytical data on various preparations gave—

—	Found.	Theoretical for $C_{40}H_{38}O_{10}N_4$.
C	64·81	65·38
H	5·04..	5·17
N	7·47, 7·68, 7·78, 7·71, 7·74	7·63
$(OCH_3)_4$ ..	16·0, 16·2, 16·2, 16·2, 16·0	16·8
$CH_3(N)$ ..	Nil	..

No differences were found in the products extracted from acid or alkaline solutions. "Alcohol condensation product" forms small yellow needles, m.p. 223°, probably not as yet obtained in a highly pure state. The solution in chloroform is yellow with little, if any, fluorescence, and this is not altered by acid or alkali. It is slightly soluble in alcohol and chloroform, less soluble in acetone, insoluble in water, dilute acids, and alkalis. 20–30 mg. amounts of perloline were refluxed with 5 ml. of N alkali in methanol-water for several hours, and volatile acid determined after removal of alcohol. Less than half a molecular proportion was found. To determine this point more exactly, 881 mg. of perloline base were refluxed with 40 ml. of 0·5 N alcoholic potash for three hours. The alcohol was removed, water and sulphuric acid added, and the precipitate filtered off. The solution on steam distillation gave about 0·1 of a molecular proportion of acid. The precipitate, m.p. 214°, was also steam distilled from dilute sulphuric acid suspension, but no acid was obtained. Oxidation of "alcohol condensation product" by the Kuhn-Roth C-methyl procedure gave no volatile acid.

The material was stable to alkali. On boiling with concentrated hydrochloric acid for a few minutes, or on refluxing a short time with 30 per cent. sulphuric acid, perloline was formed in high yield. Perloline was also formed in quantity when the material was treated with a minute amount of oxidizing agent such as permanganate in the cold. A small amount of the material was suspended in water, made alkaline, and boiled with a little permanganate. An appreciable amount of perlolidine was isolated and identified by microchemical reactions.

Acetylation of "Alcohol Condensation Product."—161 mg. of the above material was refluxed three hours with excess acetic anhydride. A red solution formed from which water precipitated a yellow flocculent material. This was extractable by chloroform from acid or alkaline suspension. Yield 127 mg., m.p. 197°, not further depressed on admixture with the original material. Analytical data gave—

$$N = 6{\cdot}94\ ;\ (OCH_3)_4 = 15.7,\ 15{\cdot}2,\ (OCCH_3) = \text{nil}.$$

The residue from hydrolysis in the acetyl determination appeared to be "alcohol condensation product."

Demethylation of "Alcohol Condensation Product."—392 mg. of this material were refluxed for three and a half hours with 10 ml. of 50 per cent. sulphuric acid. Partial neutralization after dilution gave 115 mg. of dark precipitate; in neutral solution a further 15 mg. separated, and on making alkaline with carbonate 120 mg. of red material separated. Each of these fractions was insoluble in chloroform and solvents, but dissolved in caustic alkali solutions to form deep-red solutions.

The Action of Formaldehyde on Perloline.—Perloline hydrochloride was made slightly alkaline and boiled for five minutes with 40 per cent. formaldehyde solution. A yellow crystalline precipitate formed. This was extractable from acid or alkali by chloroform, to give yellow non-fluorescent solutions. If the perloline solution is treated with a few drops of formaldehyde and heated, a brick-red precipitate is formed. This material was purified by extraction from acid solution by chloroform and was obtained as a crystalline yellow powder by addition of acetone. Analytical data gave—

—	Found	Theoretical for $C_{40}H_{40}O_9N_4$.
C	66·6, 66·9	66·66
H	5·71, 5·70	5·55
N	7·82, 7·99	7·77
$(OCH_3)_4$ ..	17·3, 17·3	17·22
$CH_3(N)$ ..	Nil	..

"Formaldehyde condensation product" melted at 198–200°, with darkening from 180°. The C-methyl determination gave no volatile acid. Boiled a few minutes with concentrated hydrochloric acid, this material formed perloline in high yield. It was stable in alkali, and with a trace of oxidizing agent (permanganate or dichromate) formed perloline. 21 mg. of this material were refluxed with acetic anhydride. On dilution a yellow precipitate formed extractable by chloroform from acid or alkaline suspension. On standing with acid this residue gave perloline in large amount.

The Action of Thionyl Chloride on Perloline.—Perloline base refluxed five hours with phosphorus trichloride was unaltered. 190 mg. of perloline base was refluxed four hours with thionyl chloride, when a deep-red solution formed and most of the perloline disappeared. Excess water was added and the solution boiled. A discoloured amorphous precipitate and some tar separated. The acid suspension was extracted with chloroform, giving a reddish-yellow solution, which was concentrated. The residue was dissolved in alcohol and thrown out by water, giving 50 mg. of amorphous discoloured yellow material, m.p. 175° (dec.), with reddening from 120°. Another preparation also melted at 175°. The purest material obtained dissolved in chloroform from an acid or alkaline solution, forming a yellow solution with slight green fluorescence. It was insoluble in water and alkalis, appreciably soluble in concentrated acids. It contained chlorine detected by sodium fusion, and was more soluble in acetone than the "alcohol condensation product," which it resembled. There was no depression on admixture with this material. Analytical data gave—

$$(OCH_3) = 14{\cdot}2 \text{ and no } CH_3(N).$$

The Action of Hydroxylamine on Perloline.—62 mg. of perloline base were refluxed with 20 ml. of alcohol and sodium carbonate and excess hydroxylamine hydrochloride. The solution went red, and after a time water was added and the alcohol boiled off. The solution was acidified and

extracted with chloroform. The red extract on evaporation left a chocolate coloured residue. It was purified by solution and precipitation by water, m.p. 100°. Analytical data gave—

$$(OCH_3) = 13{\cdot}3\text{ ; no } CH_3(N).$$

Oxidation of Perloline

Oxidation by Alkaline Hydrogen Peroxide.—In the neutral or acid solution hydrogen peroxide had no effect on perloline, but there was a ready action in strongly alkaline solution. Perloline hydrochloride in dilute aqueous solution (1 : 1,000) was divided into several portions and heated to 80°, several drops of sodium carbonate added to each, then hydrogen peroxide drop by drop, and more alkali if a ready reaction did not take place. The solution went dark brown and a strong odour rather like that of skatole appeared. A pine shaving moistened with concentrated hydrochloric acid and put in the vapour went red. After further heating the solution became light in colour and small clusters of white plates appeared. These were allowed to separate on standing, were filtered off, washed with a little water, and recrystallized from hot alcohol-water. In a few cases the yield was almost nil, generally it was appreciable. From 372 mg. of perloline hydrochloride, 86 mg. of product resulted ; from 1727 mg., 176 mg. ; and from 240 mg., 42 mg. These preparations melted at 289° (dec.), 286°, and 288°, and on recrystallization from chloroform-acetone melted at 290° (dec.). Analytical data gave—

—	Found.	Theoretical for $C_{38}H_{36}O_9N_4$
C	66·69, 65·9	65·9
H	5·32, 4·86, 5·00	5·24
N*	8·14, 8·03	8·12
$(OCH_3)_4$	18·7, 19·3, 18·6	18·1
$CH_3(N)$	Nil	..

* Kjeldahl nitrogen was low : 6·7, 6·9.

"Peroxide oxidation product" is insoluble in water even on boiling, insoluble in ether, petrol, anisole, camphor. It is slightly soluble in dioxane and acetone, more soluble in alcohol (1 : 2,000 at room temperature), and still more in chloroform and phenol. It is not visibly soluble in hot 50 per cent. hydrochloric acid or in concentrated sodium hydroxide. It is soluble in concentrated hydrochloric acid and separates on dilution. It is extractable from acid or alkaline suspensions by chloroform. The molecular weight in phenol was 202. Fusion with alkali gave the same skatole-like odour as perloline itself. Lead tetra-acetate in acetic acid was without action.

The residues from one oxidation had a strong indoloid odour. The alkaline solution was concentrated, made acid, and allowed to stand. Further "peroxide oxidation product" separated. The solution was then extracted with ether, when a few milligrams of varnish-like material were obtained. This residue had a strong odour of indole, and with *p*-dimethylaminobenzaldehyde in acid solution gave a dark-red colour. On standing a few days the odour disappeared and this reaction was no longer given. Residues from another preparation (from 500 mg. of perloline) were made acid and allowed to stand. Concentration to 25 ml. caused tarry material to separate. The solution was treated with sodium nitrite and boiled for fifteen minutes. The acidified solution was extracted with chloroform, and this solution shaken into ammonia. The solution was acidified and again extracted

with chloroform. This was concentrated in presence of water, and on cooling a discoloured material separated, weighing 50 mg. Recrystallization from acetone-alcohol gave colourless material, m.p. 204–209°. Analytical data gave—

$$N = 8{\cdot}03,\ OCH_3 \text{ and } CH_3(N) \text{ nil.}$$

Oxidation of Perloline by Acetone Permanganate.—408 mg. of perloline was dissolved in 50 ml. of hot acetone, and finely ground potassium permanganate added to the warm solution until a pink colour persisted. The whole was dried, water added, and sulphur dioxide passed in. Acid was added to remove some precipitated sulphites, and a colourless material remained undissolved. This was dissolved in boiling alcohol and concentrated, giving 63 mg. of slightly discoloured small clusters, m.p. 268° (dec.). Recrystallization from alcohol gave 41 mg. of tiny crystals, m.p. 290° (dec.). This showed depression to 253 256° on admixture with alkaline peroxide oxidation product, m.p. 290°. It is slightly soluble in chloroform, and showed no alkaloidal properties. Analyses gave—

—	Found.	Theoretical for $C_{31}H_{28}O_7N_4$.
C	66·07	65·6
H	4·94..	4·94
N	9·83, 9·85	9·86
$(OCH_3)_4$ ..	13·2, 15·6	21·8
$CH_3(N)$ ..	Nil	..

*Other Oxidizing Agents and Perloline.** —Lead dioxide in dilute hydrochloric or sulphuric acid solutions destroyed perloline, but no perlolidine was formed. Periodate in acid or alkaline solution was without action, as also chlorine water or hypoiodite. Electrolytic oxidation in 10 per cent. sulphuric acid using a lead anode destroyed perloline without formation of perlolidine, and no products were isolated.

Dehydrogenation of Perloline.—763 mg. of perloline hydrochloride was mixed with 1·46 g. of selenium powder and heated. At 280–300° there was little action, but at 330° there was a ready action, and the melt was kept at this temperature for two hours. The mixture was cooled and ground, and extracted with dilute acid. The extract was strongly blue-violet fluorescent. It was made alkaline and extracted with chloroform. About 1 per cent. of perlolidine was isolated and identified by microchemical reactions. 100 mg. of perloline hydrochloride in 0·075 ml. of acetic acid and 0·6 ml. of water was mixed with 0·62 of silver acetate and heated two hours in a sealed tube at 180° (Tafel method). Perloline was recovered unaltered.

Attempted Reduction of Perloline.—Hydrochloride solutions of perloline were treated with sulphite, hyposulphite, magnesium and ammonium chloride, sodium stannite, acid stannous chloride, and hydrogen sulphide without apparent action. Electrochemical reduction at 1·5 amp. and 30 volts (mercury cathode) was without action. 122 mg. of perloline hydrochloride were dissolved in 4 ml. of concentrated hydrochloric acid and 60 ml. of water and hydrogenated in the presence of Adams catalyst. There was no absorption of hydrogen, and the base recovered was perloline, giving a picrate, m.p. 239°. 62 mg. of perloline base in 50 ml. of ethanol were heated on the water-bath and excess sodium added. Again only perloline was recovered.

* For oxidations forming perlolidine, see Part II.

The action of boiling hydriodic acid on perloline, its salts, methyl perloline, alcohol and formaldehyde products, acetylperloline, the "nitro" body, &c., in the methoxy determination was to form demethylated materials of properties similar to those of demethylated perloline, and a trace of perlolidine. After distillation of the hydriodic acid as in the $CH_3(N)$ determination, and heating the residue, large amounts of perlolidine were formed, identified in each case by microchemical reactions. The peroxide oxidation product and the hydroxylamine material gave no perlolidine or typical demethylated material.

Alkaline Degradation of Perloline.—170 mg. of perloline hydrochloride was fused for a few minutes with a mixture of sodium and potassium hydroxides. There was at first a strong skatole-like odour which later changed to one rather like indole. The residue was dissolved in water and steam distilled. The residue from the distillation on extraction with ether gave only a trace of alkaloid. The distillate gave with *p*-dimethylaminobenzaldehyde (or vanillin) and hydrochloric acid a pink colour on warming. No other indole reactions were obtained. Perlolidine on alkali distillation gave a similar odour.

969 mg. of perloline base and 5·6 g. of soda lime were ground finely and heated in a bath at 250–330° for two hours. Oily drops and vapour came off and were caught first in an ice-cooled trap, then in a wash-bottle containing dilute acid. A strong odour escaped from these traps, similar to that given off in alkali degradation of grass. A pine shaving moistened with hydrochloric acid went blue-violet in this vapour, and later went reddish. The aqueous fraction contained oily drops and had an odour of quinoline, as well as indole-like odours, and gave strong alkaloidal reactions. Both fractions were united, when the oily drops dissolved in the acid, leaving only a trace of turbidity. The acid solution was extracted by ether, giving about 3·5 mg. of dark varnish-like material of strong indole-like odour insoluble in acids and water. It gave strong indole reactions, with *p*-dimethylaminobenzaldehyde in the cold, a pink colour going crimson on heating. Nitrite and acid gave a faint yellow colour, and vanillin and acid a pink colour. A pine shaving moistened with concentrated hydrochloric acid went reddish-violet. The aqueous solution on drying in a vacuum gave 53 mg. of very deliquescent hydrochloride, giving no indole reactions. It gave strong alkaloidal reactions and, mostly, characteristically crystalline precipitates. Aqueous picric acid gave 19 mg. of yellow needles, m.p. 183°. These were recrystallized from alcohol-water to 12 mg. of needles, m.p. 197–198° (dec.). The base from the picrate had a quinoline-like odour, but showed depression with the picrates of quinoline, 2 and 6 methyl quinolines and isoquinoline. Many substituted quinoline picrates melt about 200–230°. The mother liquor from the picrate was made alkaline and extracted with chloroform. The deliquescent hydrochloride obtained showed strong alkaloid reactions, distinct from those of the total fraction. Potassium bismuth iodide gave large plates, and this and several reactions suggested that this material was amine or piperidine-like.

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REFERENCES

(1) GRIMMETT, R. E. R., and MELVILLE, J. (1943): *N.Z. J. Sci. & Tech.*, *24*, 149B.
(2) GRIMMETT, R. E. R., and WATERS, D. F. (1943): *Ibid.*, 151B.
(3) REIFER, I., and BATHURST, N. O. (1943): *Ibid.*, 155B.
(4) SHORLAND, F. B. (1943): *Ibid.*, 159B.
(5) MELVILLE, J., and GRIMMETT, R. E. R. (1941): *Nature*, *148*, 782.
(6) PERKIN, W. H., and ROBINSON, R. (1919): *J. Chem. Soc.*, *115*, 966.
(7) JACOBS, W. A., and GRAIG, L. C. (1936): *J. Biol. Chem.*, *113*, 768.
(8) COULTHARD, C. E.; LEVENE, H. H. L.; and PYMAN, F. L. (1933): *Biochem. J.* *27*, 727.
(9) COULTHARD, C. E. (1934): *Ibid.*, *28*, 264.
(10) NIEDERL, J. B., and NIEDERL, V. (1941): "Micromethods of Quantitative Organic Elementary Analysis," II Ed., Wiley, N. Y., p. 230.
(11) WHITE, E. P. (1941): *Ind. Eng. Chem. (Anal. Ed.)* *13*, 509.
(12) — — (1941): *J. Am. Pharm. Assoc.* *30*, No. *6*, 156.
(13) GADAMER, J., and WINTERFELD, K. (1924): *Arch. Pharm.*. *262*, 601.

CASEIN MUCILAGE

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Summary

An impending shortage of imported adhesives in 1939 necessitated the revision and reorganization of the New Zealand manufacture of casein mucilage in order to suit trade requirements in regard to price, availability, and certain specific properties. Bentonite and blotting-paper pulp were the ingredients found to fulfil satisfactorily the particular inadequate conditions.

Sodium pentachlorphenate has been recommended as a preservative for casein mucilage and is now in industrial use for this purpose. A routine test for ascertaining the setting or drying time of an adhesive is described.

CASEIN adhesives may be divided into two main groups:—

(1) *Casein-lime Glue or Cement* prepared with calcium hydroxide as an essential ingredient. This adhesive may be prepared and stored in powder form or it may be manufactured with sodium silicate as an ingredient, in which case it must be utilized within a short period.

Casein-lime glue has a high tensile strength, together with a life of about twelve hours after mixing with water or aqueous solutions. There are several manufacturers of casein glue of this type in New Zealand. The glues are used chiefly by the plywood and joinery trades.

(2) *Casein Liquid Glue or Casein Mucilage.*—This adhesive is supplied in liquid form ready for immediate application and is used for many industrial purposes.

Casein mucilage is prepared in this country by dissolving lactic casein in aqueous solutions of borax, caustic soda, trisodium phosphate, or mixtures of these solvent agents. Other ingredients are added to suit specific purposes, and an efficient preservative is also incorporated. In the published recipes for casein mucilage sodium carbonate is usually included in the list of solvent agents, but in practice in New Zealand the presence of carbon dioxide has been found to be disadvantageous as it

increases the foaming or frothing tendency. Any kind of acid-precipitated casein may be employed for making mucilage, but self-sour or lactic acid casein is the only kind made in New Zealand.

Prior to the present war a very large proportion of industrial adhesives used in New Zealand in the form of mucilage were imported into the country, and the production of locally made casein adhesives of similar type was on a small scale. The manufacturers of New Zealand casein adhesives had to contend with the low price of the imported preparations, which were usually prepared from starch and dextrin. In addition, the tensile strength of the casein adhesives was unnecessarily high for many trade purposes, and for some particular uses the adhesives were too slow in drying. With the outbreak of war the importation of adhesives was restricted, resulting in an increased demand for casein adhesives. A search was therefore made for suitable low-priced materials, obtainable in New Zealand, that could be used both to lower the cost of production by reducing the proportion of casein and also to improve the drying quality of the product.

After investigation two substances were found that could fulfil these conditions—viz., bentonite and blotting-paper pulp.

(1) *Bentonite as an Ingredient.*—Bentonite, a crystalline clay of volcanic origin with micaceous structure and colloidal properties (15 parts) mixed with casein (85 parts) produces an adhesive that is of equal tensile strength with casein adhesive made wholly from casein and more resistant to water.

When the proportion of bentonite to casein in the adhesive is increased to 25 : 75 the adhesive is still of high quality and tensile strength, whilst for certain purposes in which only moderate adhesive property is necessary the bentonite-casein proportion may be increased to 33 : 67.

The bentonite is incorporated without difficulty if the following precautions are observed: (1) the size of the casein particles must not be coarser than 60 mesh; (2) the size of the bentonite particles must not be larger than 100 mesh; (3) the casein and the bentonite must be mixed thoroughly in the dry state as a preliminary procedure.

Casein-bentonite adhesive prepared as mucilage is being used in the paper, cardboard, and printing trades, also for bill-posting and warehouse despatch rooms.

(2) *Blotting-paper Pulp as an Ingredient.*—Bentonite has only a small effect on the drying property of casein adhesives. It has been found that by addition of a proportion of blotting-paper pulp a 33 per cent. reduction in drying-time is obtainable, and mucilage prepared with the addition of blotting-paper pulp is now in commercial use. Arrangements were made with the National Council for the Reclamation of Waste for an adequate supply of waste blotting-paper to meet manufacturing requirements. For preparation of the pulp the blotting-paper is torn into fragments which are boiled for twenty minutes in a 2½ per cent. aqueous solution of commercial hydrochloric acid. The liquid is then poured off from the residue of wet paper, which is stirred or mashed to form a pulp. The paper forms a pulp easily, and this pulp may be added to a hot casein solution and incorporated without difficulty. This treatment removes the ink-stains sufficiently, together with dust and dirt particles.

Treatment of blotting-paper to produce 1 cwt. of pulp requires 22 lb. of paper in 26 gallons of water containing 6½ lb. of commercial hydrochloric acid. The pulp contains approximately 86 per cent. of total moisture or 80 per cent. of excess moisture. The pulp may be used as a constituent of several types of liquid casein adhesive to suit different trade requirements.

In one formula 60 parts of pulp are added for 100 parts of dry casein; this is equivalent approximately to 9 lb. of pulp or 1·8 lb. of paper per hundredweight of casein adhesive in the form of mucilage.

Increase in viscosity due to the incorporation of blotting-paper pulp may be counteracted by the addition of sodium acetate.

PRESERVATIZATION

Prior to 1939, β-napthol had been used almost exclusively as a preservative for casein mucilage and there was no cause for dissatisfaction with its germicidal properties, but it possessed the disadvantage of causing the adhesive, on exposure to air, to turn pink and, finally, a deep reddish-brown colour. This discoloration was considered a serious fault by some industrial users, who were accustomed to white or pale-coloured starch-dextrin adhesives.

After extended trials with five possible preservatives sodium pentachlorphenate was selected as giving complete satisfaction in every respect. Thymol, which has figured so prominently in the literature on adhesives, was found to be unsuitable.

COLOUR OF CASEIN MUCILAGE

As mentioned above, the colour of the casein mucilage is of importance to some users. The colour is affected by the vessel in which the mucilage is made. Enamelled iron and stainless steel vessels are entirely suitable. Reports of the use of aluminium are contradictory. The strong alkalis used for solution of the casein would have a solvent effect on the aluminium. Galvanized iron is unsatisfactory as the zinc is dissolved by the alkalis, the interior of the vessel becomes rusty, and the mucilage is discoloured by iron salts.

Even when prepared in resistant vessels the mucilage has a light-yellow colour. When the colour is of primary importance, the mucilage may be bleached by the addition of sodium perborate in the proportion of 1 per cent. of the casein in the batch. The perborate should be added simultaneously with the preservative when the mucilage has been cooled to 60° C. (140° F.). The pH of the product will be raised by this operation and may be restored to the former value by the addition of acetic acid.

STAINING OR DYEING

One of the principal uses of casein mucilage is as a base for dye colours. In 1933 Leschanowsky(1) showed that vegetable glues play a very secondary role as binding materials for staining colours and that the preparation of staining colours is simpler with casein than with leather (animal) glue. Casein mucilages are thus being increasingly employed in the preparation of water paints used in the colouring of show cards. For this purpose most consumers prefer a fairly neutral adhesive of pH 6·8 to 7·0, and as the quality of New Zealand casein is consistent in its properties, including that of solubility, there is no difficulty in providing mucilage of the required standard.

TEST FOR ADHESION

Search of the published literature on adhesives reveals the lack of a satisfactory test for ascertaining the setting or drying time and also a rapid test for determining adhesive strength. Singer(2) states that "the paste must be tacky when manipulated between the fingers"; Becher(3) determines

adhesive strength by "a comparative method based on the force required to withdraw a glass rod from the paste." It is essential for the chemist and the works foreman to be able to assess quickly and with some degree of accuracy the properties mentioned above.

The following test has been of considerable assistance to the author and several other operators interested in the evaluation of adhesives. If carried out carefully and systematically it is useful in obtaining information regarding an unknown sample in comparison with a control of known values. The test may be used for comparing adhesive strengths if the setting-time is the same, otherwise the test is used for ascertaining the comparative setting or drying time :—

Preparation of Test Pieces.—A piece of cardboard known as "8 oz. board," measuring 5 in. by 2 in., is divided by pencilled lines into six sections measuring $\frac{5}{8}$ in. by 2 in. and the point of a sharp penknife is then passed over the dividing lines so as to partially sever the board. The card may now be folded at the sections in the shape of a concertina ; section 2 rests on section 3, section 5 rests on section 4, whilst sections 1 and 6 are left as flaps situated in a horizontal position. A stock of these test pieces is prepared and kept ready for use. "Eight ounce board" is the type which has been used mostly, but test pieces of leather and tough varieties of paper have also been found useful.

Description of Test.—Two adhesives are taken for the test, the control and the unknown ; the control sample is spread carefully on No. 2 section and the unknown sample on No. 5 section. The test card is folded so that section 2 adheres to section 3 and section 5 to section 4. It is then placed between two sheets of plywood or thick cardboard and pressed under a 14 lb. weight ; the pressing-time depends on the setting-time of the adhesives.

The aim of the test is to secure adhesion on one side of the test-card and non-adhesion or partial adhesion on the other side. A state of partial adhesion is obtained when the joint pulls apart so as to tear off a portion of the surface of the cardboard.

At the termination of the pressing-time the test card is held so that the two flaps may be grasped firmly with the thumb and two fingers of each hand respectively and is subjected to a steady, even pull. If the time has been gauged correctly, one joint will hold whilst the other will pull apart either cleanly or partially. If both joints remain in adhesion or pull apart, the test must be repeated with an alteration in the pressing-time, or the control sample must be replaced with one of different adhesive strength or setting property. The test card could be adapted to quantitative measurement by attaching clips to the flaps of the test card to which are fastened the ends of two wires. One wire would be attached to a fixed point and the other would pass over a pulley in the same horizontal plane to a scale-pan. Weights would be added to the scale-pan until one of the parts gave way.

ACKNOWLEDGMENT

Grateful acknowledgment is made of the co-operation of Dr. T. R. Vernon in carrying out the bacteriological and mycological work.

REFERENCES

(1) LESCHANOWSKY, G. (1933): *Chem. Zentr. II*, 2767.
(2) SINGER, W. (1934): Gelatine, Leim, Klebstoffe, 2, 6–7.
(3) BECHER, CARL, Jr. (1935): Gelatine, Leim, Klebstoffe, 3, 54–58.

BIOLOGY OF *ANOBIUM PUNCTATUM*

PROGRESS REPORT

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Summary

This report, after a brief review of literature relating to *Anobium punctatum* de Geer in New Zealand, describes the techniques used in rearing the borers with the object of utilizing them as test insects to evaluate timber therapeutants. Aspects of biology not previously dealt with are described.

INTRODUCTION

THIS laboratory is investigating the possibility of using *Anobium punctatum* de Geer as a test insect for evaluation of timber therapeutants. The problem has resolved itself into two phases, firstly investigation and standardization of technique for therapeutant testing, and secondly mass breeding of supplies of adult beetles and larvæ for these tests. At present adults are obtained by hand collection from buildings and discarded timber, but this is unsatisfactory as it is time-consuming and the supply is both limited and uncertain, while larvæ obtained by dissection from discarded timbers are variable in size and of uncertain age. During the course of the work, investigations on the biology have been necessary. Results of these, together with incidental information, are presented in this paper.

No extensive account of the biology of *A. punctatum* in New Zealand has yet been published. In literature there are, however, many incidental references, a few of which contain relevant observations. Kirk (1905) drew attention to the large amounts of starch present in kahikatea (*Podocarpus dacrydioides* A. Rich). He also examined other less-susceptible timbers and found that timber attacked by larvæ of the furniture beetle contained either starch or glucose, usually the former. Speight (1918) reported on *Anobium* attack of Canterbury Museum timber specimens. While there is no indication as to whether the specimens were heart or sap wood, he stated that all the common hard- and soft-wood building timbers, with the exception of miro, were attacked.

Cockayne (1919) stated that in general it was only to sap-wood of kahikatea and kauri that the most damage was done, though heart-wood of both was liable to attack; in rimu only sap-wood was attacked. He stated that larvæ may tunnel for one to three years, and that adults emerged in November and December, when a beetle laid from eighty to one hundred and fifty eggs each day in crevices, old exit holes, or in short holes bored into the wood.

Thomson (1922) reported Kirk's findings on the starch and glucose aspects of *Anobium* attack, and quoted Riddell as stating that very few timbers were exempt from attack, which he considered was a question of age and dryness, and that certain substances in the wood must evaporate or change before the insect would attack it.

Miller (1925) stated that the sap and heart wood of both soft- and hard-wood timbers was attacked, but that, so far as known, insignis pine was not damaged by *Anobium*. Eggs were laid in crevices or exit holes, and larvæ emerged after fourteen to twenty-eight days; pupal period was two to three weeks, and the whole life-cycle occupied twelve months.

Smith and Forbes (1944) stated that *Anobium* confined its attention to sap-wood, principally of soft-woods. The life-cycle varied from one to three years, and eggs were laid in cracks, crevices, joints, and exit holes—never on smooth surfaces. They stated that kiln-drying did not make wood immune from further attack.

Denne, Spiller, and Kelsey (1944) found the emergence period in Auckland to be from mid-October to the last week of January, with the peak in December.

IDENTIFICATION

New Zealand specimens of the furniture beetle were submitted to the Division of Insect Identification, United States Department of Agriculture. They were identified by Mr. Fisher as *Anobium punctatum* de Geer, indistinguishable from American representatives of the species.

PARASITES

In the course of this work adults of a wingless chalcid ectoparasite were found to be common during the *Anobium* flight period. Specimens were identified by Mr. A. B. Gahan, of the United States Department of Agriculture, as *Theocolax formiciformis* Westwood, recorded previously in New Zealand by Gourlay (1930). Large numbers of an ectoparasitic tarsonemid mite were sometimes found when infested timber was dissected for larvæ. Comparison with specimens identified by Mr. H. Womersley showed these mites to be *Pyemotes ventricosus* Newport. The importance of these two parasites in the bionomics of *A. punctatum* is at present unknown.

BREEDING TECHNIQUE

Sexing of Beetles.—Marked sexual dimorphism is shown by both the last ventral abdominal segment and the apical chitinized setose lobe or telson that covers the genitalia from above. These differences are tabulated below and illustrated in Fig. 1, A and B :—

—	Female.	Male.
Telson	Apical margin sinuate ..	Apical margin strongly convex.
Last visible sternite ..	No depression ..	Bears marked depression.

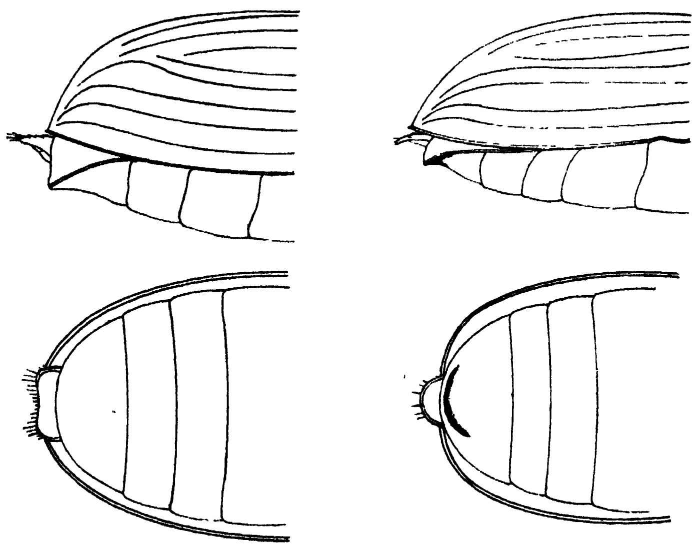
No difficulty was experienced in sexing large numbers of beetles using these features; though the telson of the female appears to possess a definite sinuation in the distal margin, depth of the sinus is governed by the angle at which the telson is viewed, as it is a concavo-convex plate. Sometimes the margin may appear to be truncate. However, the strongly convex plate in the male readily separates it from that of the female. Individuals were placed in small glass phials and sexing carried out under a binocular microscope with a magnification of approximately 20x. As beetles were sexed they were also inspected for injuries, and any with damaged tarsi, legs, or antennæ, other injuries, or with abnormal genitalia were discarded. The activity, measured by the time taken in climbing the sides of the phials, gave an indication of the physical condition of the insects.

Initially it was assumed that females mated only once, but there is now evidence that they may mate three or more times during the course of egg-laying. The fact is important, since in the mated pair technique—to be described later—there is no certainty that the females have not already laid some of their eggs.

METHODS OF USING ADULTS IN CAGES

The objects of the work have been to obtain known numbers of eggs laid on wood blocks of limited size, and to study effects of various conditions such as preservatives, humidity, wood species, and seasoning on hatching of eggs and survival of larvæ. Four techniques that have been used are described below.

(*a*) *Random Material*.—Fifty adults were placed in each cage without reference to sex. The technique was not satisfactory, because extreme variation in the number of eggs laid per cage prevented uniformity of



A B

[*Photo by M. J. Dahlberg.*

FIG. 1.

Fig. 1A: Female lateral and ventral views of terminalia. Fig 1B: Male lateral and ventral views of terminalia.

infestation and resulted in some blocks being without eggs, while others were so heavily infested that accurate counting of eggs was impossible. These differences were traced to variations which occurred in the sex ratio of material from different sources (Table 1), and the technique was abandoned after the 1942–43 season.

(*b*) *Mated Pairs*.—During the 1942–43 flight period material was kept in a large jar and pairs of beetles united in copula were isolated in small phials. The percentage of usable material obtained in this way was low (less than 5 per cent.), presumably because many mated and disengaged during the night or at times when observers were not present to remove the pairs. The method was subsequently modified to prevent mating, when observers were absent, by isolating individual beetles in tubes at the

conclusion of each day and emptying them again into a large container next day. About one-third of the female beetles was obtained as mated pairs, and the method has the advantage that the average number of eggs per female (Table II) was always higher than that obtained by any other technique. Variation was greater, however, making uniform infestation difficult to obtain, and this, together with the excessive amount of labour involved, suggests that, except for small experiments, the technique is unsatisfactory.

(c) *Male and Female.*—In this method all residual beetles from the large containers were sexed twice a week and equal numbers of males and females were selected from these for use. The average number of eggs per female was lower by this technique than by the mated pairs method (Table II), but this is to be expected when it is considered that all virgin females in a day's collection were subsequently removed as mated pairs.

Only this method will be used in future work and all beetles will be sexed and used as they are brought to the laboratory.

(d) *Mass Material.*—In addition to beetles used as mated pairs and those used in the male and female technique there was a relatively large number of females which were discarded from the experiments because of injuries or abnormalities. This material was used to bulk infest timber from which in time the entire supply of beetles will be obtained. At times it may be expedient to use this material to obtain uniform egg infestations on wood blocks, and although this method has not been investigated in detail, results obtained in a few preliminary experiments are encouraging. Surplus male and discarded female beetles were placed together with four or five wood blocks in a cage similar to type III. The latter was 4 in. in diameter and was stored in a vacuum-type desiccator over saturated sodium chloride solution. The hole in the desiccator lid was lightly plugged with cotton-wool, which allowed slow diffusion of air and moisture, but at the same time stabilized conditions. Each day blocks were removed for egg counting and then returned or replaced by new blocks, depending upon whether sufficient eggs had been laid. At the same time dead beetles were removed and fresh beetles added. Fairly uniform infestations of eggs were obtained, and the method warrants further investigation.

CAGES

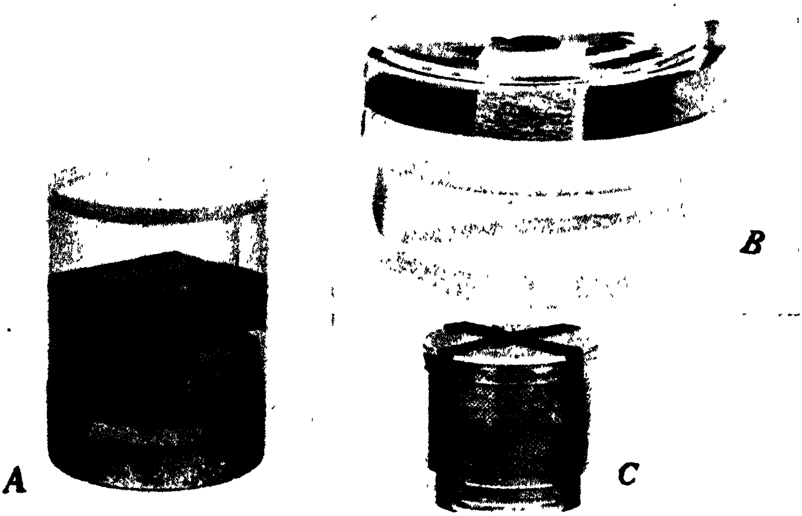
Type I: Fig. 2A (adapted from Prell (1927)).—A tin 3¼ in. diameter by 1¼ in. in depth has fine wire gauze set into the lid. Over this is placed a celluloid cylinder 3¼ in. high with fine muslin cemented into the top. Water is placed in the tin and blocks of wood and beetles enclosed between gauze and muslin. Its purpose is to produce a fairly high humidity around timber samples when kept under ordinary room conditions of temperature and humidity. Black paper was placed on top of these cages to reduce the light intensity.

Type II: Fig. 2B.—Described by Becker (1938), the cage consists of halves of a 3½ in. by 1⅛ in. petri dish separated by a wire gauze partition; a small annulus is formed round the cage which permits limited diffusion of air and moisture. As there was a tendency for dishes to shift during handling, the gauze disk was so fixed to the top dish by means of a horizontal band of ½ in. adhesive tape that the annulus was not blocked. The halves of the dish were held together by passing another band of tape over the whole assembly. Wood block and beetles are enclosed in the upper portion of the cage.

Type III : Fig. 2c.—This consists of a cylinder of wire gauze 2¼ in. in diameter and 2 in. high. Ends are closed by halves of small petri dishes kept in place by rubber bands passing over top and bottom of the cage.

TEMPERATURE AND HUMIDITY CONTROL

A room with controlled temperature and humidity was run continuously at 22·5° C. and 75 per cent. relative humidity. Maximum variation in temperature did not exceed ± 0·5° C. in any one month. Humidity control was not of the refrigerated type, and tended to deteriorate when humidity of the outside air rose during the summer months. Because of this, humidity of the type II cage was stabilized by placing in the lower compartment a saturated solution of sodium chloride known to give a relative humidity of 75·3 per cent. in the air above. In experiments at controlled humidities



[*Photo by M. J. Dahlberg.*

FIG. 2.

Fig. 2A : Cage type I. Fig. 2B : Cage type II. Fig 2C Cage type III.

type III cages were stored either in large desiccators or in special unit containers, and interior humidities controlled by caustic potash solutions of known concentration, using data given by Buxton (1934).

TIMBERS USED

Small blocks, either an inch cube or 1 in. by 1 in. by ½ in., of clean, straight-grained, sap-wood kahikatea were used in all work other than that on the susceptibility of different timbers. For the latter were used sap-wood blocks approximately 3 in. by 1 in. by 1 in. of kiln-dried and air-dried timber of different species. Blocks were conditioned to the respective humidities of the experiment for some weeks before they were infested, and thus their surfaces at least would be in equilibrium with the atmosphere. Blocks for type I cages were not conditioned, but immersed in water for half an hour before use.

VARIATIONS IN SEX RATIO OF ADULTS

Introduction of the sexing technique showed immediately that there was considerable variation in the sex ratio from day to day and more particularly from one type of collecting-ground to another. Results are shown in Table I:—

TABLE I.—SEX RATIO OF ANOBIUM ADULTS

Source.*	Collections.	Beetles.	Percentage of Females.
Bin	29	741	47·7
Cages	8	78	43·6
Insectary	14	342	34·5
Factory	33	3,835	25·8
Houses	12	429	40·3
House	5	350	15·7
Miscellaneous	23	414	38·9
Totals	124	6,189	30·4

* For location and other details of source, see paper of Denne *et al.*, 1944, *J. Sci. & Tech*, 26 (Sec. A.) 152–154.

The investigations indicate that the male : female ratio is approximately equal, as those collecting-grounds in which it was possible to make observations at regular intervals throughout the day yielded a ratio in the vicinity of 1 : 1. In other instances when collections were made at irregular intervals the percentage of females captured was low. The explanation of this lies in the behaviour of the beetles, which mate normally soon after their emergence from wood, and while still in copula retreat into exit holes and crevices in the timber. After an hour or so, males disengage from females and return to the wood surface, while the latter remain in the tunnels, &c., to lay some of their eggs. The females later reappear to go through the same procedure, and the time occupied in ovipositing is greater than that spent on the surface. As males spend most of their time on the surface of timber, it is apparent that at any one time the percentage of males will be high.

This explanation is borne out by the following observations. In a bin where infested timber was closely stacked, the few beetles emerging were unable to move freely, so that opportunities of finding members of the opposite sex were small, and under these circumstances collections showed that the male : female ratio was approximately equal. In situations such as walls of buildings, however, where there was no restriction on movement and where the *Anobium* population was high, the proportion of females collected was low, as many had mated and disappeared into exit holes and crevices to oviposit.

On five occasions "swarms" of beetles have been observed on the surface of pieces of timber, and in one case where the "swarm" was collected and sexed there were 167 males and 3 females. It was also noticeable that after a piece of timber had shown the phenomenon of "swarming" very few beetles were taken from it in any subsequent collection.

EGGS

(a) *Egg-laying.*—To ascertain the most suitable type of surface for oviposition, sap-wood blocks were subjected to puncturing, scoring, cutting, cracking, and rasping. In most cases a dressed piece of the same wood

was placed in the cage as check. From an egg-laying point of view results indicate that the physical nature of the wood surface is as important as the timber species. Totara (*Podocarpus totara* A. Don) is normally a non-susceptible timber, but on one occasion more eggs were laid on roughened totara than on finely sandpapered kahikatea kept in the same cage. A wide range of incision angles was found to be approximately equal in suitability for oviposition sites. Apparently the chief factor governing choice of a site is the opportunity of firmly wedging an egg into a small hole or crevice. Eggs were not normally deposited on surfaces of dressed timbers, but where one piece was adjacent to another, eggs were often inserted between the two. Normally most eggs were laid on the end grain of experimental blocks, not so much to preference for this position, but that sides of the timber were usually dressed and so afforded very few sites for egg-laying. On roughened blocks it was possible to obtain a much greater number of eggs on sides than on end grain surfaces.

In type I cage it was found that large numbers of eggs—ranging from 27 per cent. to 60 per cent.—were laid on the muslin tops and that the percentage of eggs laid here gave a rough indication of the susceptibility of the wood in the cage. Most eggs were pushed half-way through the muslin; some were forced right through the mesh. Other sites where eggs were laid included corks of tubes in which beetles were enclosed, glass surfaces, and black paper used to cover type I cage. Eggs were always attached to the surface by an adhesive, even when wedged into holes and crevices.

The number of eggs laid per female was not significantly different on any of the following timbers: *Pinus radiata* D. Don air-dried and kiln-dried, rimu (*Dacrydium cupressinum* Soland.) air-dried and kiln-dried, totara kiln-dried, tawa (*Beilschmiedia tawa* Benth. and Hook. f) kiln-dried, and matai (*Podocarpus spicatus* R. Br.) kiln-dried.

(*b*) *Number of Eggs laid.*—Table II shows the great variation in numbers of eggs laid per female :—

TABLE II.—ANOBIUM EGG-LAYING

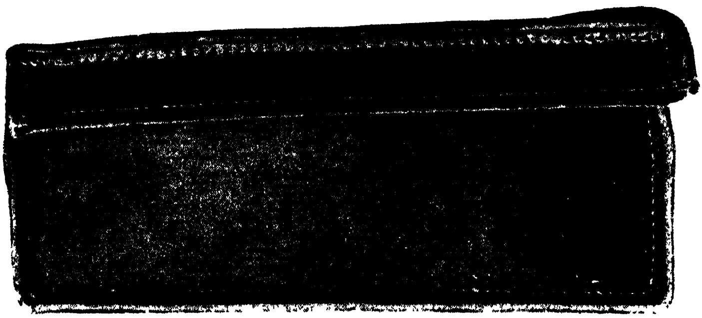
Technique.	Cage.	Conditions.	Total Females.	Average Eggs per Female.	Range per Cage.
Male and female	Type III	22·5° C. and approximately 75 per cent. R.H.	24	14·7	4·7–20·0
,,	Type III	22·5° C. and approximately 75 per cent. R.H.	96	15·5	3·2–22·0
,,	Type I ..	Room	370	14·7	0·5–21·5
Mated pairs ..	Type III	22·5° C. and approximately 75 per cent. R.H.	24	44·8	21·3–72·7
,, ..	Type II..	22·5° C. and approximately 75 per cent. R.H.	80	26·8	7·8–54·8
,, ..	Glass jars	Room	48	21·4	..

(*c*) *Hatching.*—Under the same conditions, the incubation period varies from six to ten days on wood blocks. There were numerous cases where larvæ did not emerge from eggs laid on muslin for as long as five weeks. These were usually fully developed, and after cutting a small hole in the egg capsule, remained in the egg. Some eggs remained pellucid during the normal incubation period, and in these the embryos had not developed; eggs with developing larvæ changed to an opaque creamy colour.

Apparently orientation of the eggs does not affect hatching. The larva emerges from the egg surface in contact with the timber and commences to tunnel into the wood with the capsule still in place. Where eggs were cemented to plane surfaces and not wedged in, larvæ were often unable to commence tunnelling, whereas eggs cemented into crevices provided an ideal base from which larvæ could commence boring.

In experiments carried out under laboratory temperatures and humidities (cage type I experiments), 92·2 per cent. of eggs laid either on muslin or on wood blocks hatched, while in experiments using cage type II at 75 per cent. relative humidity, 89·6 per cent. of eggs hatched.

In a series of controlled experiments at different relative humidities and a temperature of 22·5° C. no eggs hatched below a relative humidity of 45 per cent., and although larvæ developed fully they appeared to be unable to emerge from the egg capsule. In the range 50 per cent. to 65 per cent. R.H. hatching was always below 80 per cent. and sometimes as low as 54 per cent., while above 65 per cent. and up to 95 per cent. R.H. more than 80 per cent. of eggs invariably hatched.



[Photo by M. J. Dahlberg.

FIG. 34.—Exit holes of *A. punctatum* in leather suitcase.

The maximum hatching of eggs for any large group of blocks was 93 per cent., and all hatching figures both under optimum controlled and room conditions appear to lie between the extremes of 80 per cent. and 93 per cent. Work is being continued and will be published at a later date.

TUNNELLING OF LARVÆ

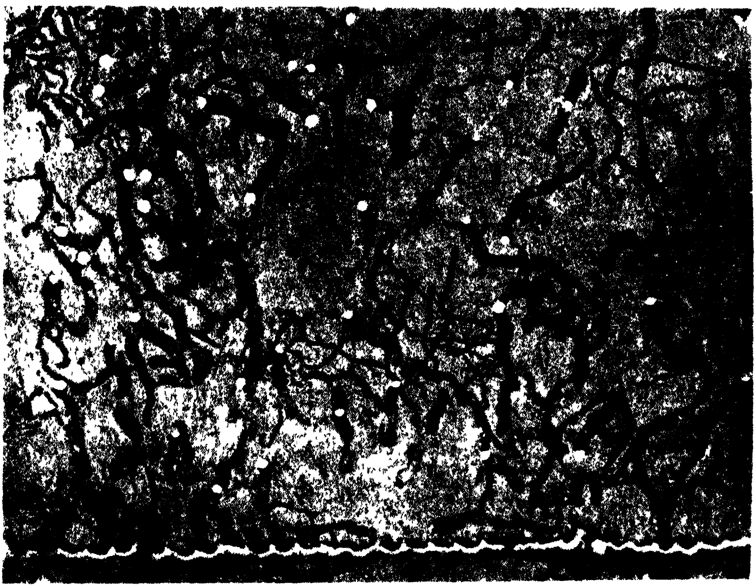
As tunnelling proceeds, frass pellets collect in the egg capsule, which may eventually be forced off due to tight packing of pellets. Larvæ experienced some difficulty and often were unsuccessful in boring into kiln-dried matai and rimu. The timber species (apart from seasoning) does not exercise any apparent influence as far as initial tunnelling is concerned. Newly hatched larvæ can live for long periods without food, as is shown by the fact that in two cages from which blocks had been removed larvæ were found on cage sides nineteen days after the eggs on the muslin cage tops had hatched. The first moult occurred when larvæ had tunnelled in for about their own length, and during the process they were usually found with their heads directed outwards.

In experiments under laboratory conditions (cage type I) 99·8 per cent. of the larvæ from hatched eggs tunnelled into the wood. Where timber was infested eighteen months previous to dissection, boring was found to be

most extensive in kahikatea. Tunnels in both rimu and matai were much smaller than in kahikatea, those of matai being slightly larger than those of rimu. In totara several tunnels had been started and extended to ⅛ in., but no live larvæ were found.

LIFE-CYCLE

The length of the life-cycle is variously reported in literature; most authors regarding it as being one year. This is apparently based on observations of an annual flight period, but overlooks the fact that there may be a series of overlapping generations. Reikhardt, Karakulin, and Isachenko (1930) stated that the life-cycle is as short as six months in hot climates, but Fisher (1932) reported from actual breeding experiments that it was three years on *Cotoneaster* wood in England. Experiments on kahikatea suggest that the life-cycle is three years, and further studies on sap-wood timbers are in progress to confirm this.



[*Photo by M. J. Dahlberg.*

FIG. 3B.—Workings of *A. punctatum* in cardboard filling of leather suitcase.

Air-dry sap-wood of matai, rimu, kahikatea, and totara were infested with eggs and stored under room conditions. Sixteen months later blocks were sectioned on a wood microtome, when it was found that larvæ taken from kahikatea were very much larger than those from any other timber. Larvæ varied to a slight extent in each block, but there was considerably more variation in size of larvæ taken from different blocks of kahikatea. Larvæ from rimu and matai were small compared with those from kahikatea, being no larger than six-months-old larvæ taken from kahikatea; larvæ from matai were consistently larger than those from rimu. These larval differences, together with observations on tunnel size, indicate that timber species affect rate of development and possibly length of the life-cycle.

Although *A. punctatum* normally breeds in timber, it attacks other materials. In the first instance a wood-fibre wallboard was infested with *Anobium* eggs in the laboratory, and after fourteen months live larvæ were dissected out. The frass was normal, but it is not yet known whether the life-cycle can be completed in this wallboard. In the second instance it was found breeding in the cardboard filling of a leather suitcase. Exit holes in the leather of the suitcase are shown in Fig. 3A and the extensive workings in the cardboard are shown in Fig. 3B. Adults were bred out and when compared with known *A. punctatum* de Geer were found to be typical. Wood-fibre wallboard and cardboard filler are highly modified wood products, suggesting a wider adaptability in nutrition of *A. punctatum* than usually supposed.

ACKNOWLEDGMENTS

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REFERENCES

BECKER, G. (1938): The Testing of the Insecticidal Effects of Wood Preservatives, using *A. punctatum* as the Test Insect. *Arb. Physiol. Anjew. Ent. Berl.*, *5*, 357–360.

BUXTON, P. A. (1931): The Measurement and Control of Atmospheric Humidity in relation to Entomological Problems. *Bull. Ent. Res.*, *22*, 431–47.

COCKAYNE, A. H. (1919): The Wood-borer and Its Control. *N.Z. J. Agr.*, *18*, 198–199.

DENNE, WINSOME; SPILLER, D.; and KELSEY, J. M. (1944): Research on *Anobium punctatum* de Geer. The Flight Period at Auckland. *N.Z. J. Sci. & Tech.*, *26* (Sec. A), 152–154.

FISHER, R. C. (1932): In *Report of the Forest Products Research Board for the Year 1930*, p. 29. His Majesty's Stationery Office, London.

GOURLAY, E. S. (1930): Preliminary Host-list of the Entomophagous Insects in New Zealand. *N.Z. Dept. Sci. & Ind. Res. Bull. 22*, p. 6.

KIRK, H. B. (1905): On the Occurrence of Starch and Glucose in Timber. *Trans. N.Z. Inst.*, *37*, 379–380.

MILLER, D. (1925): Forest and Timber Insects in New Zealand. *N.Z. State Forest Service Bull. No. 2*, p. 50.

PRELL, H. (1927): On a Hibernating Cage for Insects. *J. Econ. Ent.*, *20*, 830–834.

REIKHARDT, A. N.; KARAKULIN, B. P.; and ISACHENKO, V. B. (1930): "Pests of Timber and Their Control." 60 pp. Moscow, 1930. (In *R.A.E.*, *18*, 188).

SMITH, J. H., and FORBES, A. C. (1944): How to Defeat Wood Borers. *N.Z. J. Agr.*, *68*, 83–88.

SPEIGHT, R. (1918): New Zealand Timbers and the Borer. A Note on the Susceptibility of New Zealand Timbers to the Attack of the Borer *Anobium domesticum*. *N.Z. J. Sci. & Tech.*, *1*, 142–144.

THOMSON, G. M. (1922): "The Naturalisation of Animals and Plants in New Zealand," pp. 292–293. Cambridge University Press.

A TERMITE DAMAGING COCONUT-PALMS ON SUWARRO ISLAND: *CALOTERMES (NEOTERMES) RAINBOWI* HILL

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[*Received for publication, 5th March, 1945*]

Summary

1. The termite described does considerable damage to coconut-palms.
2. Recommendations are made that steps be taken to control the damage to plantations.
3. These descriptions include several new characters for this species.

DURING 1941 there were several reports that coconut-palms had been so badly damaged by termites that large numbers of the trees were being snapped off by the gales that sometimes sweep the islands in this area. Suwarro (or Suwarrow or Suvarov, as it is also called) is a small island in the Danger Group, Pacific Ocean, and, together with the island Puka Puka, is densely covered with coconut-palms on which the Native population of this group of islands largely depends for food. The Natives are becoming rather concerned at the numbers of palms falling due to termite injury. The last report was that the trees on Puka Puka Island had been almost completely destroyed. This is probably due in large degree to the gales themselves apart from possible termite damage, but, nevertheless, the photographs accompanying one of the reports by an officer in the Public Service indicate that the question of controlling the termites should be investigated in the near future.

This termite has not been recorded previously from the Danger Group of islands, and as there are several points in which these termites differ from Mr. G. F. Hill's descriptions of *C. rainbowi* and *C. samoanus* the writer is including a full description of them; in spite of these differences, however, it is probably one of these two species. Some of these differences are as follows: Hill's description of *C. rainbowi* indicates that the prothorax of the alate has a convex posterior border, whereas in those examined in New Zealand this border is always concave; he also says the second and third antennal joints of the soldier are about the same length, whereas the writer's specimens all had the third antennal joint about half as long again as the second. *C. samoanus* has the postclypeus of the soldier without conspicuous hairs, whereas the species described here has two long and two shorter hairs; Hill's soldier pronotum is not as wide as the head, whereas the Suwarro one has a pronotum as wide or wider than the head. It is not proposed to consider the Suwarro termite as a new species, but to redescribe it as *C. (N.) rainbowi*, since Mr. T. G. Greaves, of the Council for Scientific and Industrial Research, Australia, considers that there is little doubt that it is this species.

The material examined consists of a series of immature forms of all castes lent by the Cawthron Institute, Nelson, to whom it was sent in 1941 by C. E. Clarke from coconut-palms, and a series in the possession of the Auckland Museum bearing the label "Suwarrow Is., 1941, B. C. Robertson. 59/42." The Museum material contained several mature alates and soldiers,

together with numerous nymphs, and for this reason the colour descriptions apply to this series and not to the immature Cawthron material; however, the latter possess all the other described characteristics.

The wing venation of this termite is exceedingly variable (two sets of wings are shown in Fig. 1), even on the two sides of the same individual. Some have a vein arrangement closer to subgenus *Calotermes* and several soldiers possess a lengthened third antennal joint that further complicates matters. However, the majority are typical *Neotermes* species.

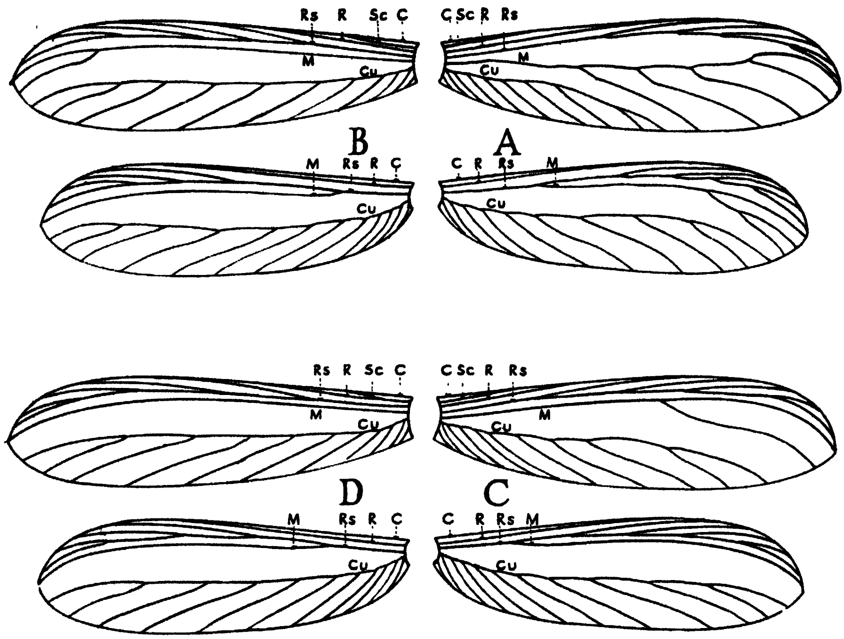

FIG. 1.

DESCRIPTIONS

Alate (Fig. 2A)

Size.—Large, but variable; average length without wings is about 11 mm. by 3 mm. wide. Fore wings with wing-stumps are about 16 × 4 mm. and the hind wings about 14·5 × 4 mm.; they are very slightly wider than the fore wings. The wing-stumps of the fore and hind wings are about 2 × 1·5 mm. and 0·8 × 0·7 mm. respectively. The pronotum is about twice as wide as long.

Colour.—In general is brown to dark brown; head dark brown in front, shading gradually to brown posteriorly; labrum golden yellow. The pronotum has a wide dark-brown band round the margins, while it shades to brown in the centre. The meso- and meta-thoraxes and the abdomen are brown, with darker-brown longitudinal stripes in the median line of each of the former and on the posterior margins of each abdominal tergite. Legs are golden yellow.

Head.—Longer than wide, counting labrum. Labrum tongue-shaped, with a cluster of long and short spines distally and numerous very short spines over the rest of the surface. Clypeus white, with concave anterior border. Postclypeus bears four long, slender spines projecting forwards. Ocelli large and conspicuous and close to centre and dorsal to eyes; each has a long spine in front of it and projecting backwards across the ocellus. Eyes large and well developed. Epicranial sutures conspicuous. Sparsely arranged, long setæ clothe the head. Antennæ of 18–21 joints. The first three segments are brown and the rest golden yellow; the second and third joints are approximately equal and together as long as the first, which is widest; the fourth is the smallest, and the remainder become progressively longer; all except the first two bear one ring of very long, and one or two rings of short, spines; the two first segments possess only very short spines.

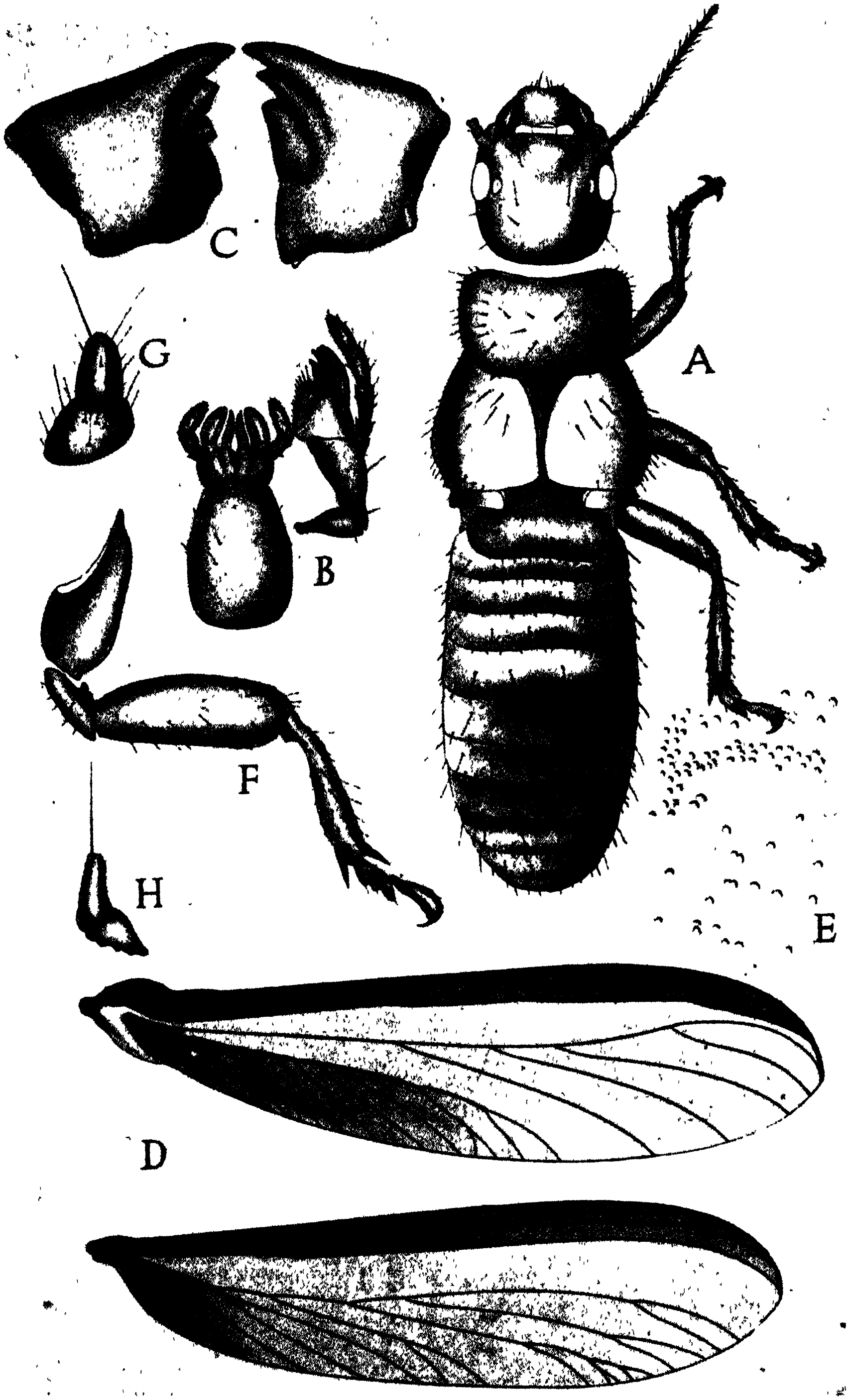

FIG. 2.

Maxillae (Fig. 2B).—The submentum is an irregular oval, wider posteriorly and bearing about eight long spines. The somewhat triangular cardo articulates with the submentum nearly half-way down the side; the cardo has a peculiar Y-shaped chitinous thickening, the ends of the arms of the Y forming the articular facets for attachment of the stipes. The stipes is an irregular rectangle bearing distally the fleshy galea and heavily chitinized lacinia. The latter terminates in two stout fixed thornlike claws, and on its inner border is flattened and beset by a single row of stout marginal spines; the base is broad and occupies most of the distal end of the stipes. The maxillary palp is of the usual five joints—two short proximal and three more or less equal distal joints—and bears numerous long and short spines. The stipes has only two long spines. The second maxillæ consist of the submentum, a short fleshy mentum with median, longitudinal groove, and distal median cleft, and the usual glabrous, fleshy, glossa, and paraglossa each side of the cleft. The labial palp is of three short joints bearing short spines. The mentum bears a few short spines.

Mandibles (Fig. 2C).—Of the usual *Calotermes* type. The right mandible has a stout, conical apical tooth and a slightly shorter but similar one just posterior to it: then there are two wide, flat grinding surfaces separated about midline by a slight groove. The left mandible has the usual stout apical tooth and two short chisel-shaped teeth with opposite angles so that they form an M shape; posterior to these is a broad convex grinding-surface. Both mandibles articulate with the head by ball and socket joints, there being one of each on each mandible.

Pronotum.—This is almost twice as wide as long, much wider than the head, and reniform in shape, though there is a slight posterior sulcus; the anterior border is wide and concave. It bears numerous long and short spines.

Wings (Fig. 2D).—The anterior wing-stumps are long and wide and extend well beyond the posterior margin of the mesothorax and almost cover the hind wing-stumps, which extend only half-way along the metathorax, and are almost as wide as long. The front edge of the anterior stumps is strongly convex (see Fig. 2D) and bears a few long and short spines about the distal half, it also bears a single long spine on the centre of each vein just anterior to the suture, and a few long spines on the rest of the stump. The fore wings (Figs. 1 and 2D) show variable arrangement of the veins; sometimes the median runs through the centre of the wing about midway between the radial sector and the cubitus (Fig. 1A), which in this case reaches only just beyond half-way along the posterior edge. If the median sends off posterior branches as sometimes occurs (Fig. 1C), the cubitus is again shortened, but normally it extends to the distal end of the wing (Figs. 1 B and D). Sometimes the subcostal (?) does not come off the radial till beyond the suture (Fig. 1D). In typical members there is a costal, subcostal, radius, radial sector, and median, close together and heavily chitinized, and a cubitus extending to near the wing-tip; the radial sector usually sends 3–6 major diagonals up to the costal margin, and the median has 0–3 major branches to the distal wing margin. The cubitus has a large number of major and minor branches to the posterior wing margin. In abnormal forms the median may have as many as five major branches (Fig. 1A). The *hind wing* does not vary to the same extent as the fore wing and typically possesses a costal, radius, radial sector, median, and cubitus. The radius is normally unbranched and joins the costal about half-way along the wing; the radial sector sends from 5–9 branches up to the costal beyond the radius; the median comes off the radial sector about a quarter the length of the wing from the suture; it is connected to the vein above by numerous short branches, and also sends off numerous posterior irregular branches; all these veins are arranged close together and possess a few widely scattered, short spines; the cubitus passes through the centre of the wing and reaches almost to the wing-tip, sending off numerous major and minor branches to the posterior wing margin. There are no spines on the costal edge till about half-length, and from then on there are numerous spines rather more widely spaced than on the fore wing. The posterior wing margins of both wings are free from spines; micrasters are plentiful on the wing membrane and are in the form of small scattered papillæ (Fig. 2E).

Legs (Fig. 2F).—Of normal type with no great enlargement of the femur. The femur, tibia, and tarsal joints all bear numerous long, in addition to shorter, spines, and the tibiæ all possess three very long, stout spurs. The empodium is particularly well developed.

Abdomen.—All segments bear very long spines. There are ten visible tergites, and in the male there are eight complete sternites and one divided longitudinally in mid-line into two small lateral plates; the female shows six complete sternites and two divided longitudinally into lateral plates. Cerci (Fig. 2G) are of two segments and densely spinose, the spines being set on conspicuous raised papillæ. The styles (Fig. 2H) are short and terminate in one very long and two or three short spines.

Soldier (Fig. 3A)

Size.—About 12 × 2½ mm. The head plus mandibles is about 5 × 2½ mm. The mandibles are about 2 × 1 mm.

Colour.—In general is golden yellow on thorax, abdomen, and legs. The head is dark brown in front, shading gradually to light brown on the back of the head. Mandibles are black, with very dark-brown bases. The first three antennal segments are brown and the rest light brown. The prothorax has a narrow brown margin. Labrum golden yellow; clypeus white with a small, yellowish-brown patch each side of mid-line. Eyes and sutural spots white.

Head.—Slightly dorsoventrally compressed; sides almost parallel, but tapering very gradually. The frons is flat and has a long, gradual slope to the mandible bases. Epicranial sutures conspicuous and with a white sutural spot just above and inside the eyes. Eyes conspicuous, but white. Labrum tongue-shaped and with two very long and numerous shorter spines. Clypeus white, with yellowish-brown markings and a slightly concave anterior border. Postclypeus pronounced and bearing two very long and two shorter spines projecting forwards. The general head surface bears numerous long spines. The antennæ have 14–17 joints and are about 2½–3 mm. long. The first antennal joint is long and stout and bears a few very short spines; the second segment is less than half as long as the first and bears short spines; the third joint is half as long again as the second, and it and succeeding segments each bear a ring of very long and one or two rings of short setæ. The antennæ have a conspicuous raised rim round their insertions.

Mandibles (Fig. 3B).—Short and rather narrow for the size of the termite. The bases, however, are greatly enlarged. Right mandible has a broad topped tooth just anterior to half mandible length and another similar one just posterior to half length. From here the mandible has a shallow concave curve back to the widest part of the base: there is a very slight groove in the centre of this curve. Left mandible has two short, blunt teeth about the anterior quarter, a short, flat-topped tooth with a groove at each end about half mandible length and then a very wide, triangular, basal area with the apex about half-way down the molar edge of this area. The mandibles articulate with the head by a ventral ball and dorsal socket arrangement.

Maxillae (Fig. 3C).—The submentum may be divided into a posterior, slender area with strongly concave sides, and an anterior broad oval area with a slight groove in each side where the cardo articulates. The lateral borders are very heavily chitinized, and there are about six stout spines at the widest part. The anterior end is made up of a whitish, semitransparent area overlying the base of the small mentum. The mentum is short and weakly chitinized: it has the usual median, longitudinal groove and distal median cleft. The first maxillæ are composed of small, rather arc-shaped cardo with Y-shaped thickenings where the points of articulation lie; a somewhat rectangular stout, stipes with two long spines on the outer border; a five-jointed palp, the distal three segments of which bear, in addition to the usual shorter spines, a few exceptionally long setæ; the fleshy, outer galea and the heavily chitinized, flattened lacinia terminating in two stout, fixed thornlike spines of equal length. The second maxillæ are similar to those of the alate.

Pronotum (Fig. 3A).—About 1¼ mm. long and 2¾ mm. wide; much wider than head and reniform in shape with very slight posterior sulcus. It has a lateral arch, and the anterior rim is not raised. There is a wide, shallow anterior sulcus. It bears a few long spines on its surface and numerous long and short setæ round the borders.

Legs (Fig. 3D).—The femoræ are not greatly swollen, but form a long oval. All joints of the legs bear long and short spines with the exception of the coxæ. The tibial spurs are unusually long and slender. Femoræ, tibiæ, and tarsi become progressively longer from front to rear.

Abdomen.—The segments bear conspicuously long setæ about the centre and a row of shorter spines towards the posterior margins. The cerci (Fig. 3E) are short and stout and have conspicuous raised papillæ bearing the long setæ. The styles (Fig. 3F) are rather long and bear a very long terminal spine and two or three shorter spines.

CONTROL OF TERMITES IN LIVING TREES

The following notes have been taken from the available information on this subject. For some fifteen years Ceylon workers have given a great deal of attention to control of termites (eight species of *Calotermes* and two of *Coptotermes*) infesting living tea-bushes. By 1934 nearly two hundred thousand bushes had been treated successfully by paris green or white arsenic dusts, both of which gave 100 per cent. control without raising the

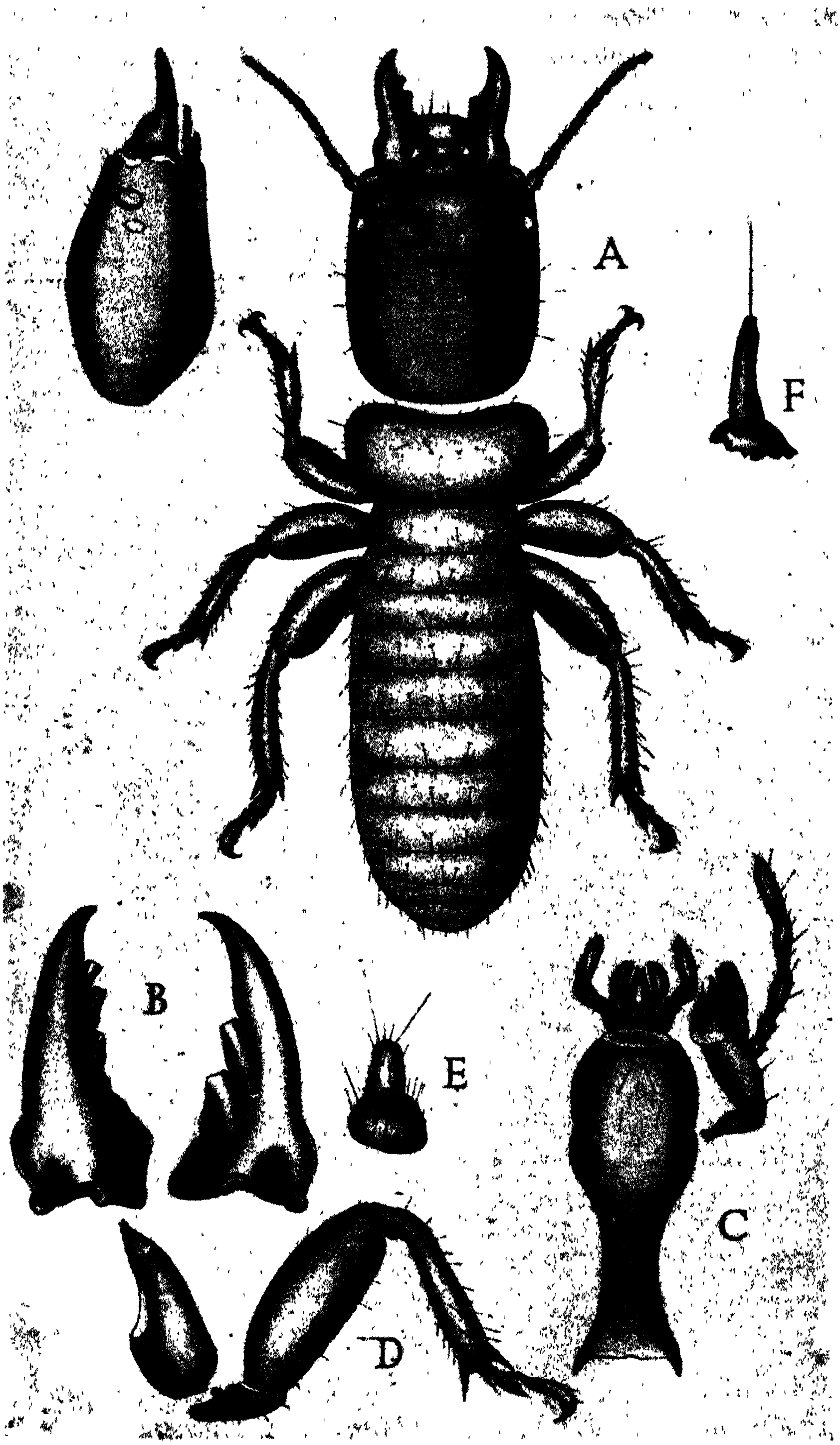

FIG. 3.

arsenic content of the leaves at all, as revealed by exhaustive studies by the Government Analyst in Ceylon. Though coconut-palms are commonly attacked in Ceylon, there are no references to any special treatments, and they are apparently treated by the same technique as for tea-bushes. This consists of drilling ¼-in. diameter holes into infested limbs and blowing from $\frac{1}{12}$ oz. to $\frac{1}{16}$ oz. of arsenic dusts in by means of a syringe.

Cost of treatment using Native labour worked out at about 1½ cents per bush, and one Native could do 180 bushes a day. Native labour proved satisfactory if the men were given reasonable supervision, but they lost interest and were careless if given a definite job with fixed hours. It took an average of 3½ lb. of dust to treat 1,000 tea-bushes at the above rates.

It is particularly stressed that chief attention should be paid to preventive treatment such as covering all scars and injuries with coatings of asphaltum, paints, resins, tars, &c., but no definite mixtures are given in the literature.

Termites very seldom penetrate the living tissues of trees, and therefore it is very necessary that any breaks in this tissue allowing access to dead heartwood should be sealed off. It is obvious that control of termites actually in the trees would be practically useless unless there was some means of preventing other termites from gaining entry later, and it is suggested that some sticky material such as that recently developed by Dr. W. Cottier at the Plant Diseases Division, Department of Scientific and Industrial Research, would be quite suitable for preventing termites from again attacking the trees. These materials consist of kauri-gum, resin, castor oil, and beeswax in varying proportions according to the consistency desired, but further experiments would be necessary to determine whether or not they would stand up to the extremes of day and night temperatures under tropical conditions.

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I wish to thank the Auckland Museum and the Cawthron Institute for the use of their material.

REFERENCES

HILL, G. F. (1942): Termites (Isoptera) from the Australian Region. *Proc. Roy. Soc. Victoria*, 38, 95.

KOFOID, C. A. (1934): "Termites and Termite Control."

SNYDER, T. E., and BANKS, N. (1920): "A Revision of Nearctic Termites." *Bishop Mus. Occasional Papers*, 12. *Dept. Agr. Ceylon Reports for 1928–33.*

A METAL THERMOREGULATOR

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IN the construction of a thermoregulator of the toluene-mercury type for controlling a bath in the vicinity of room temperature with an accuracy of the order $\pm 0{\cdot}01°$ it is the usual practice to use a glass container, often in the shape of a cylindrical bulb. A helical coil of glass tubing is sometimes used in order to expose a larger surface area and thereby increase sensitivity. Because of the low heat conductivity of glass there is a considerable lag in the response of such regulators to temperature fluctuations in the bath, which can be overcome by using a metal container for the toluene-mercury

regulator. Several designs have been used for special work, but it is worth while drawing attention to their potentialities in routine work, since they compare favourably with glass regulators in ease of construction, accuracy, cost, and robustness, and there would seem to be every justification for their more widespread use.

The photograph shows a thermoregulator, constructed in these laboratories, using a 12 ft. length of copper tubing of $\frac{5}{16}$ in. external diameter and $\frac{1}{32}$ in. wall, wound in a helix of diameter $3\frac{1}{4}$ in. and height 12 in. The lower end is closed by soldering and the upper end attached to a bent glass tube in which is the mercury-toluene junction. This portion could be simplified considerably if the regulator were constructed of iron tubing, but if, on account of its superior thermal conductivity, copper tubing is employed, then precautions must be taken against mercury being sucked back into the copper tube while the instrument is being filled or adjusted to another temperature. The function of the bent glass capillary tube with two bulbs is evident from the photograph. The side arm with stopcock is only used if the thermostat has to run at a series of temperatures at each of which adjustment of the regulator has to be made; it can be dispensed with in the case of a thermostat running continuously at one

FIG. 1.—The thermoregulator. It has been necessary to show the instrument lying on its side. The top is on the left-hand side.

temperature. In use the regulator is immersed so as to just cover the horizontal glass tubes; thus only the very small volume of mercury in the capillaries above this level is exposed to the uncontrollable variations of room temperature. The electrical contact is effected near the top of the right-hand capillary tube, round which a wider tube, sliding on a cork, is fitted to absorb any overflow of mercury during adjustment. The fine adjustment is made in the usual way by moving the upper platinum wire on a screw.

Several methods of making copper-glass seals are available, most of them involving platinum or palladium chloride. It has been found that a satisfactory join can be attained by first silvering the glass tube by deposition from ammoniacal-silver-nitrate - invert-sugar solution, copper plating the coating by electrodeposition from a copper sulphate solution and finally soldering to the copper tubing.

Such regulators have given excellent service at 25°, controlling the temperature to $\pm 0{\cdot}002°$ or less. They have been found equally satisfactory for controlling baths at temperatures below that of the room, for which purpose the regulator controls a magnetically operated clamp on the exit pipe from a refrigerated tank into the thermostat.

THE NEW ZEALAND

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PHYSICAL PROPERTIES OF THE FOUNDATION ROCK AT THE PROPOSED DAM SITE AT MARAETAI, ON THE WAIKATO RIVER

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Summary

Tests were made on the natural rock at a section of the Maraetai gorge on the Waikato River at various depths in both banks for physical properties such as (1) specific gravity, (2) water absorption, (3) water permeability, (4) compressive strength, (5) shear strength, (6) modulus of rupture, (7) Young's modulus of elasticity in compression, and (8) in flexure. The rock was tested in an oven-dried condition and also after four or more days' water immersion at atmospheric temperature. It was found that the wet rock showed a marked decrease in strength and elastic moduli.

The stone tested lay in two main sheets, the upper being well weathered, light, and porous, and the lower more dense, compact, and stronger. Furthermore, the properties varied with depth in each of the two sheets tested, specific gravity, strength, and elastic modulus increasing with depth, with a corresponding decrease in water absorption and water permeability. The following extreme ranges of values were observed: (1) S.G., 1·83 to 2·16 for dry stone; (2) water absorption, 6·4 per cent. to 15·6 per cent. on the dry weight; (3) water permeability varies from $0 \cdot 5 \times 10^{-7}$ to $6 \cdot 0 \times 10^{-7}$ cubic feet per second flow through 1 square foot area of stone, 1 ft. thick, due to a head of water of 1 ft.; (4) compressive strength, 2,000 lb. to 6,800 lb. per square inch for dry stone, and 1,230 lb. to 4,900 lb. per square inch for wet; (5) shearing strength, 600 lb. to 2,100 lb. per square inch for dry stone and 500 lb. to 2,000 lb. per square inch for wet; (6) modulus of rupture, 130 lb. to 500 lb. per square inch for dry stone, and 125 lb. to 385 lb. per square inch for wet: (7) modulus of elasticity in compression, $0 \cdot 34 \times 10^6$ to $1 \cdot 12 \times 10^6$ lb. per square inch for dry, and $0 \cdot 25 \times 10^6$ to $0 \cdot 97 \times 10^6$ lb. per square inch for wet: (8) modulus of elasticity in flexure, $0 \cdot 14 \times 10^6$ to $0 \cdot 41 \times 10^6$ lb. per square inch for dry, and $0 \cdot 12 \times 10^6$ to $0 \cdot 34 \times 10^6$ lb. per square inch for wet. The values in (7) and (8) are mean values for E over a range from about zero stress to one-third or one-half of the ultimate crushing stress.

INTRODUCTION

AN investigation was undertaken by the Dominion Physical Laboratory, Lower Hutt, for the Hydro-electric Branch of the Public Works Department, Wellington, of the chief physical properties of the natural stone at Maraetai at a dam site selected for a projected hydro-electric power scheme. The crest of the dam, it is estimated, will be about 300 ft. above the foundations, probably making it one of the highest dams in the Southern Hemisphere. The installed capacity of the power-house will be 180,000 kilowatts with five machines.

Following a preliminary survey by engineers of the Hydro-electric Branch and one by Mr. J. A. Healy of the Geological Survey Department, a site was selected in the Maraetai gorge, a cross-section of which is shown in a reproduction of a Public Works Department drawing EHN 1098/5. In this drawing are shown the inspection drives and shafts which were excavated, from which stone was sampled at 15 ft. intervals and forwarded to Wellington for cutting and testing (see Fig. 1).

The testing equipment and procedure, test results, and some general observations are set out in the report, together with a number of photographs and graphs typical of the results obtained.

Geologically, the stone is known as a welded tuff—in particular, an ignimbrite—and is regarded as being the result of a series of explosive volcanic eruptions in clouds of viscous particles, which became welded together as they settled and cooled. The material occurs in three nearly horizontal layers or sheets, of which practically all the upper sheet has weathered away at the section of the river examined, but still exists over most of the area.

The middle sheet, about 70 ft. thick, consists of a fine granular matrix in which is embedded large inclusions of pumice and glass crystals up to almost $\frac{1}{4}$ in. across. It is a relatively light and weak material, well jointed and weathered. The lower sheet, more than 300 ft. thick, is much more homogeneous, dense, and hard, with inclusions of tiny crystals of glass and quartz. It is a darker grey in colour than the sheet above it. A series of horizontal joints 2 in. to 6 in. apart clearly marks the interface between the two sheets. Throughout the site examined the country is well jointed with steeply inclined shrinkage cracks or joints.

I. SCOPE OF REPORT

The following physical properties of the natural rock at Maraetai were tested, and suggested mean values have been set out in tabulated form: (1) specific gravity; (2) water absorption; (3) water permeability; (4) expansion of the dry rock in absorbing water; (5) compressive strength; (6) shearing strength; (7) modulus of rupture; (8) Young's modulus of elasticity in flexure; (9) Young's modulus of elasticity in compression; and (10) Poisson's ratio.

The detailed test results, not shown in this report, indicate that the stone is isotropic with respect to such properties as strength and elastic modulus. Its appearance bears this out, the material being a close-grained, strongly welded tuff with no indication of any stratification apart from the occasional lenticular form of its inclusions. There were no consistent variations of test values when the tests were conducted along different directions at right angles with respect to the same block from which individual test specimens were taken. For this reason, the mean values are calculated on data obtained from each site, irrespective of directional differences.

The rock was tested in two conditions—dry and wet. The dry condition was established by drying the stone in a large oven maintained at about 120° C. for at least four days, when the weight was observed from preliminary tests to have reached approximately a steady value. The wet condition was the result of at least four days' immersion in water at atmospheric temperature; in most cases the immersion lasted two to three weeks. Although saturation did not generally occur in four days, the stone usually reached 98 per cent. of the maximum wet weight in this time. As there was a definite decrease in strength and in the moduli of elasticity through water immersion, the majority of tests were done on wet stone. It seems reasonable to assume that the rock will eventually reach a nearly saturated condition after the dam is filled with water.

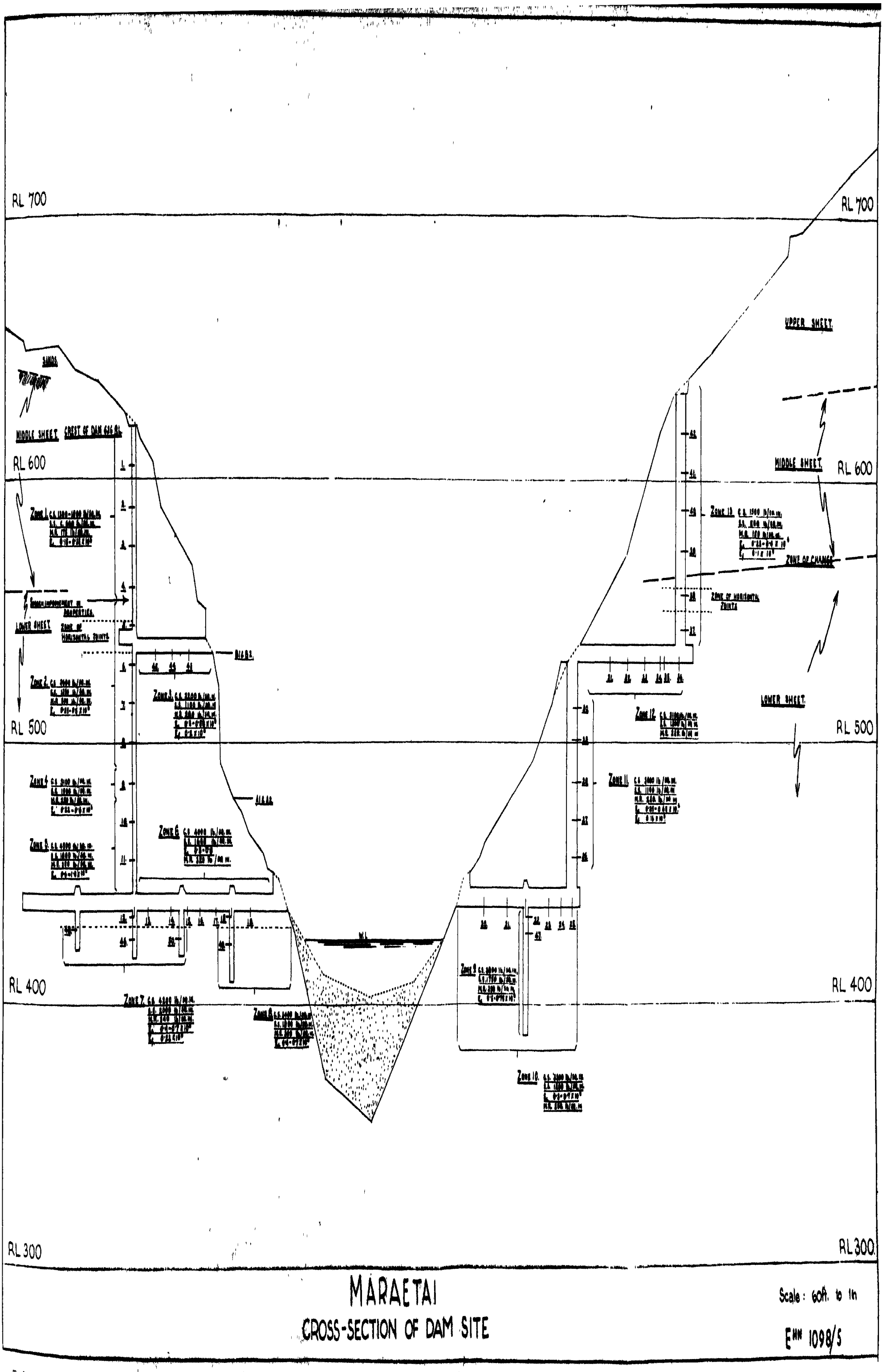

Fig. 1.—Chart ENN 1098/5 divided into strength zones.

Stone was sampled from fifty different places, each place being marked with a number (two with letters) as shown in P.W.D. drawing EHN 1098/5. The vertical or horizontal spacing between neighbouring sampling sites was approximately 15 ft.

The scope of the tests was thus to determine reasonably accurate values for the various physical properties of the dam site, covering a comprehensive portion of the cross-section of the river gorge examined, to give some basis for formulating the design of the dam structure. Together with the " small specimen " data obtained from these tests must be taken into account the natural features of the country, such as the fact that it is well jointed—more so in some places than in others—features that may be entirely absent in small specimen testing or may influence the test values—*e.g.*, reduce a strength value—to an extent that would not occur in the material *in situ*. In Section IV some suggestions are offered as to dividing the river gorge section into a number of zones, each having the mean overall properties set out. It is probable that, for design purposes, several zones will be grouped, reducing the number to two or three.

II. DATA OBTAINED FROM THE TESTS

In the table on pp. 101–110, setting out the mean values of the test results, the various vertical columns have been numbered to facilitate the explanation of the table. In column 1 the number of the sampling site is given, and the data obtained from measurement or test are set out in two horizontal rows—the upper row gives the data for the dry stone and the lower one for the stone in the wet condition.

III. DESCRIPTION OF THE TESTING PROCEDURE, WITH NOTES ON THE DATA TABLE

Sampling, Marking, and Cutting

Sampling.—The selection of sampling places was done at the proposed dam site, which was visited by Messrs. W. A. Bloodworth and M. Fisher of the Hydro-electric Branch and Mr. K. Williamson of this laboratory.

It was arranged to obtain, where practicable, samples from the places numbered 1 to 50, A1, A2, B1, and B2 in P.W.D. drawing EHN 1098/5. The samples were taken as the drives and shafts were being tunnelled. The contractors were requested to reduce the charges of explosive used in the immediate vicinity of the sampling places and to drill through to the next head of rock to remove the blocks—the country is well jointed here with steeply inclined shrinkage cracks or joints. It was considered that the shattering effect of the explosives would not be carried past a joint and that a sound sample could be removed from the head next to the ones carrying the explosives.

Some blocks received were found to be badly shattered on sounding and could not be used, but the majority were quite sound. From each sampling site two blocks of approximately 2 ft. × 2 ft. × 1 ft. 3 in. were taken.

Marking.—As the blocks were removed, the top horizontal face of each was marked " Top," and with the site number—*e.g.*, 2/30—meaning that it was site 2, 30 ft. from the top portal. The blocks were crated in river sand and railed to Wellington, where they were sent direct to the Fletcher Holdings stone-yard, Webb Street. Arrangements were made for the stonemason to cut as many test specimens as could be obtained of as comprehensive a selection as possible. The specimens were all rectangular solids or cubes, and the mason marked on each the site number on the original block. The

face parallel to the horizontal top face of the original block was lettered "Top." From this it could be observed in testing whether the maximum stress set up in the test piece would be equivalent to a vertical or horizontal one on the site. The results indicated that the material was isotropic.

Cutting.—Owing to the highly abrasive nature of the inclusions in the stone—large pieces of glass and small quartz crystals—the cutting had to be done with a steel circular saw, the rim of which was impregnated with carborundum set in a suitable matrix. The blades were 12 in. to 16 in. in diameter rotating at about 3,500 r.p.m. The stone in the upper sheet—sites 1 to 4 and 39 to 42—was inclined to become damaged at the corners and edges, owing to the tearing-out of the harder inclusions. The lower, more strongly welded samples, however, gave good clean edges and corners.

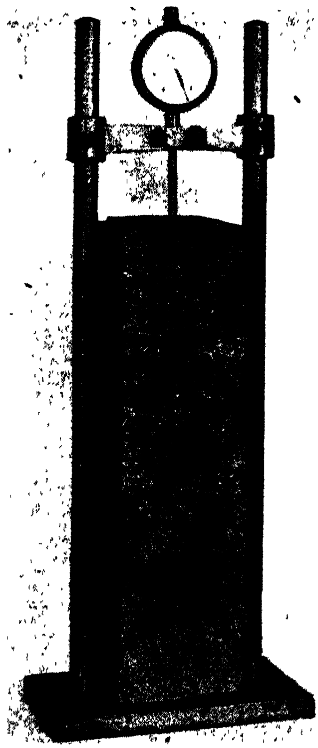

FIG. 2.—Apparatus for measuring expansion due to water absorption.

Linear Measurements and Weights

On receipt of the blocks at the Laboratory they were all measured to 1/40 in. with a steel rule and a measuring stand—the distance of the mid-points of opposite faces being measured. The dimensions of the faces marked "Top" were measured and written down first. The blocks were then placed in a large oven maintained at about 120°C. to dry, or immersed in a tank of water until such time as they were tested—at least four days later. Immediately prior to testing, the blocks were weighed to 1 dram. The blocks in the oven were allowed to cool in the testing room, no provision being possible for keeping the air specially dry. Each test piece was given a distinguishing letter or letters.

Specific Gravity

This was calculated from the linear measurements and weights described above, as many test specimens being used as practicable. In general, at least six values of each condition were obtained and the means taken. Although some extreme variations occurred, as much as 3 per cent. in a particular site, this might be attributed to large inclusions, variation in the moisture content, or experimental error. The majority of results were well within 1 per cent. of the mean values. It was not practicable with such a volume of work to crush the stone prior to drying out, &c., nor was the extra accuracy regarded as being necessary.

Columns 3 and 4 of the data table give the dry and wet values respectively of the bulk specific gravity so determined.

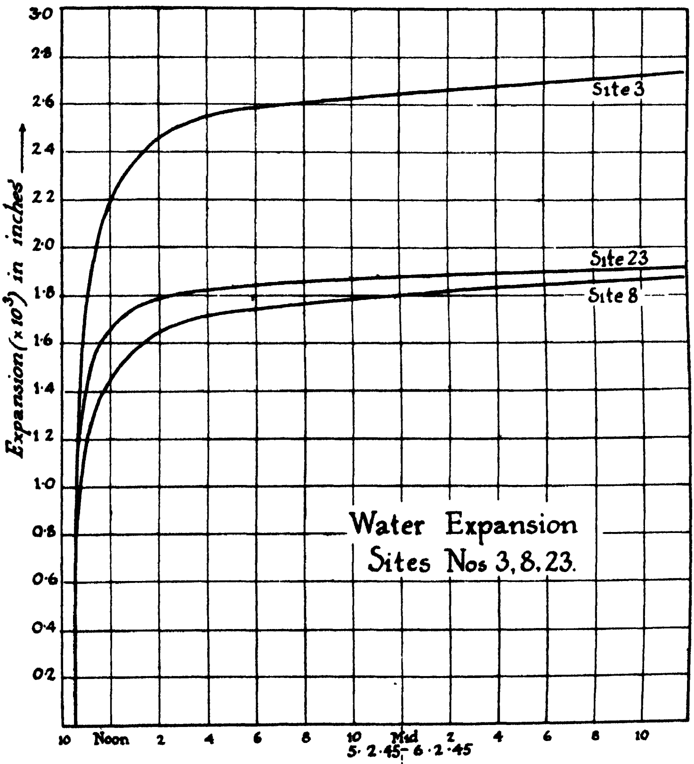

FIG. 3.—Typical water expansion curves.

Water Absorption and Expansion due to Water Absorption

The water absorption was calculated as a percentage on the dry weight from the formula—

$$\text{Water absorption (per cent.)} = \frac{W2-W1}{W1} \times 100$$

where W1 = weight of the dry block.
W2 = weight of the wet block.

The data were obtained either from the specific gravity measurements or from weight measurements of the tests for the expansion of dry stone in absorbing water.

In the latter tests, 12 in. × 3½ in. × 3½ in. blocks were used. The dry block after weighing was set up in the stand shown in Fig. 2, with the dial gauge in contact with the top surface of the stone, through an extension piece, having its lower end spherical. Three such stands and blocks were set up at a time and placed in an empty tank. The dial gauges were then set at zero. Water was gently siphoned in and the expansions of the blocks were recorded every few minutes for the first half-hour, and then every four hours or so for about three days till the test was completed. The initial expansion was quite rapid and 98 per cent. of it occurred in twenty-four hours with most specimens. The gauges were read to 0·0001 in. and the temperatures of the water and of the room were observed at each reading of the gauges. The temperature changes were not great, as a small enclosed portion was erected in a room and maintained at a temperature of about 20°C. ± 4°C. Corrections were made for the thermal expansion of the steel stand, which was heavily greased periodically to prevent rusting, and a graph was plotted to show the relation, expansion of stone *v.* time in hours. This is shown in Fig. 3.

Column 5 gives the data for water absorption per cent. and column 9 the range of values for the coefficient of expansion—*i.e.*, expansion per unit length—with the mean value immediately below, for the various sites on which measurements were made.

Water Permeability

The apparatus for measuring the water permeability of rock is a standard form of equipment used for concrete. The equipment is illustrated in Fig. 4.

It consists essentially of a welded open steel box of ½ in. steel plate with internal dimensions of approximately 7 in × 7 in. × 4½ in. The bottom (7 in. × 7 in.) face has a square hole 5 in. × 5 in. cut centrally, and the lid is a steel plate approximately 10 in. × 10 in. × ½ in. which can be bolted down against the open face of the box with a rubber gasket to make an air- and water-tight seal. Four heating elements with nichrome tape wound round natural sindanyo sheets are mounted on the inside of the four sides with sufficient clearance to allow the 6 in. × 6 in. × 3 in. test blocks to rest squarely on the bottom of the steel box.

To set in a block of stone for testing, the inside bottom of the box is brushed with hot liquid bitumen and the stone pressed against it. Hot liquid bitumen is poured into the space between the stone and the sides of the box. A current of 4 to 5 amperes through the element keeps the bitumen liquid and prevents air cavities being formed; at the same time the steel box is kept hot by passing a Bunsen burner round it. A sheet-metal pyramid with handle is placed over the upper face of the stone to prevent bitumen flowing on to it. The appropriate amount of heating, &c., is a matter of experience to give a properly sealed stone. The lid is then bolted on tightly and two rubber pressure tubes are connected one to each of two nipples in the lid of the steel box and the free ends of the hoses are connected to air and water connections of the water tower.

The diagram illustrates the principle of the water tower, which consists essentially of a tank with a gauge glass and scale to indicate the quantity of water passing through it. Water from the ordinary mains can be run up into the tank and at the same time fill the steel box, which has an air bleeder valve to remove any enclosed air. The water cock is closed, and air from a steel air cylinder is permitted to enter, through a reduction valve, the top of the water cylinder. The water is thus forced through the pores in the stone, and the rate of flow can be determined at any desired pressure.

It was observed that at a given pressure the rate of flow through a sample of stone tended to vary slightly and might reach different steady values on two consecutive days.

Observations of the temperature of the water passing through excluded the possibility of the variation being caused by change in the viscosity of

FIG. 4.—Water permeability test.

the water. Initially, the flow of water decreased with time due to silting up of the stone with particles in the water supply. A filter was introduced between the mains and the water tower but changes were still produced—varying by as much as $\pm$ 10 per cent. on the mean flow. It was concluded that the main cause could be ascribed to alternate blocking up and freeing

of the capillaries of the stone with fine particles already loose in the stone through prior weathering action or other natural causes.

The general procedure was first to apply the estimated working pressure of the site being tested upon the water and measure the rate of flow after it had become steady. As was expected, the flow was markedly reduced after the stone was saturated. This measurement was observed over a period of one to two days and water temperatures noted. The pressure was then held at approximately 25, 50, 75, 100, 125, and 150 lb. per square inch respectively for periods of one to two hours each and the rates of flow measured. The results were plotted on a graph, pressure *v.* rate of flow, which showed invariably a linear relationship as is illustrated in Fig. 5.

In the table of data, column 6 assumes the high-water level in the dam to be at site 42 and gives in pounds per square inch the calculated pressures

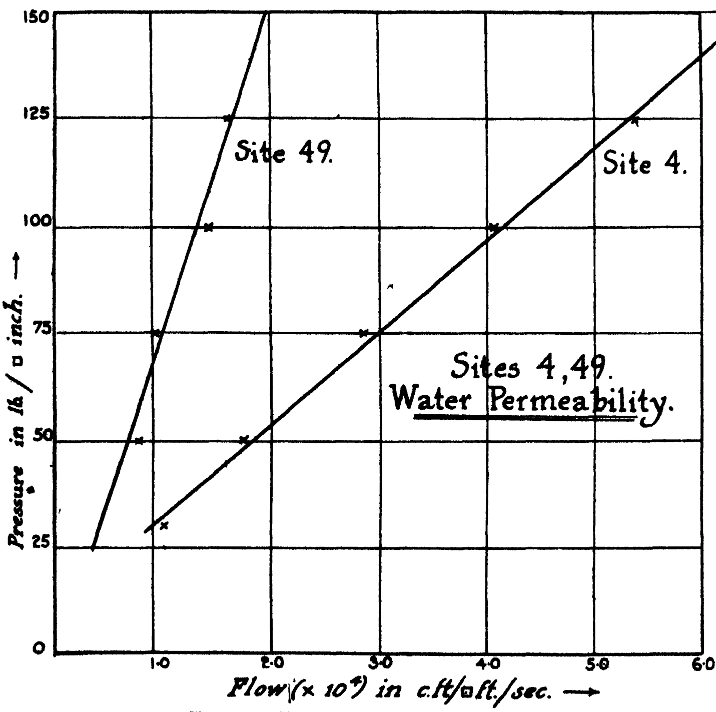

FIG. 5.—Water permeability curves.

due to the water head at the lower sites on which permeability measurements were made. Column 7 gives the flow of water in cubic feet per second per square foot of surface, through a block of stone 3 in. thick, having a difference of pressure on the opposite faces equal to the water head at that site.

Column 8 gives the flow under similar circumstances due to a pressure difference of 150 lb. per square inch—*i.e.*, an equivalent water head of about 290 ft. This set of values is useful for comparing the permeabilities of the stone at various places under equal pressures.

Compressive Strength

A standard form of test piece was adopted—a 3 in. cube—but a number of specimens of different sizes and shapes were also tested and the data used (see Fig. 6).

The stone was placed with sheet lead on the bearing faces between two ⅜ in. thick steel plates. Each specimen was placed centrally on a spherical seating and the whole placed centrally on the lower platen of a Denison hydraulic compression testing machine, 50 tons capacity, registering loads by every 0·2 ton.

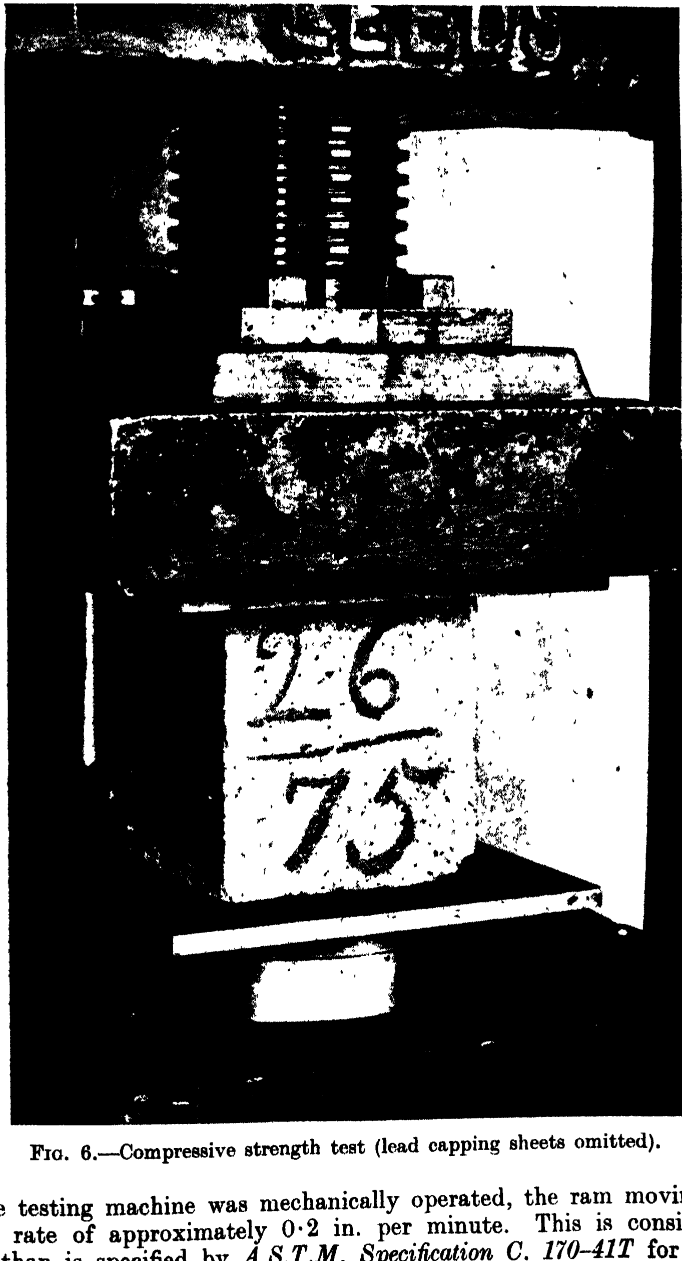

FIG. 6.—Compressive strength test (lead capping sheets omitted).

The testing machine was mechanically operated, the ram moving at a steady rate of approximately 0·2 in. per minute. This is considerably faster than is specified by *A.S.T.M. Specification C. 170–41T* for testing natural stone, which specifies a speed not greater than 0·05 in. per minute,

but comparative tests carried out on a new Riehlé 300,000 lb. capacity compression testing machine on a small number of varied samples gave no significant or consistent differences from the data obtained on the Denison machine.

The testing machine had been twice checked during the course of the tests with two steel proving rings to full capacity, and a calibration curve drawn in each case. Care was taken to observe the direction of the applied load on the test blocks in relation to the face marked "Top," but no consistent differences were observed between the tests made with direction of the load parallel to it from those with the load at right angles.

Failure in the cubical blocks of the lower sheet generally occurred suddenly and frequently with the sides bursting out. Fracture occurred along shear planes varying between 50° to 70° with the horizontal. Blocks having a length : width ratio considerably greater than unity—*i.e.*, 1·5 : 1 or over—frequently showed the characteristic double pyramidal form of fracture, with bearing faces as the bases of the pyramids and the centre

FIG. 7.—Typical types of failure in compression.

of the block as a common apex (see Fig. 7). As long blocks appeared to be relatively weaker than cubical ones, a correction given in *A.S.T.M. Specification C. 170–41T* for converting the compressive strength values for long blocks to the equivalent values for cubes was applied to test specimens with a length : width ratio greater than unity, viz.—

$$S_c = \frac{S_r}{0{\cdot}778 + 0{\cdot}222\ {}^b/_l}$$

where b = breadth of the block.
l = length of the block.
S_r = strength of the rectangular block obtained from compression test.
S_c = the equivalent strength of a cubical block.

This formula, in general, corrected the measured strength of the long blocks to a value close to the mean of the cubical specimens of the same material. In a few cases where the correction appeared to give the specimens rather high values, an arithmetical average was taken of the S_r and the computed S_c values.

Mass Effect.—A number of 8 in., 5 in., and 3 in. cubes, respectively, of the same sample blocks from several sites were tested in the Public Works Department's new 300,000 lb. capacity Riehlé compression testing machine, but no consistent differences in compressive strength could be obtained due to specimen size. This indicated that a 3 in. cube was not too small to give a satisfactory measure of this property of the material.

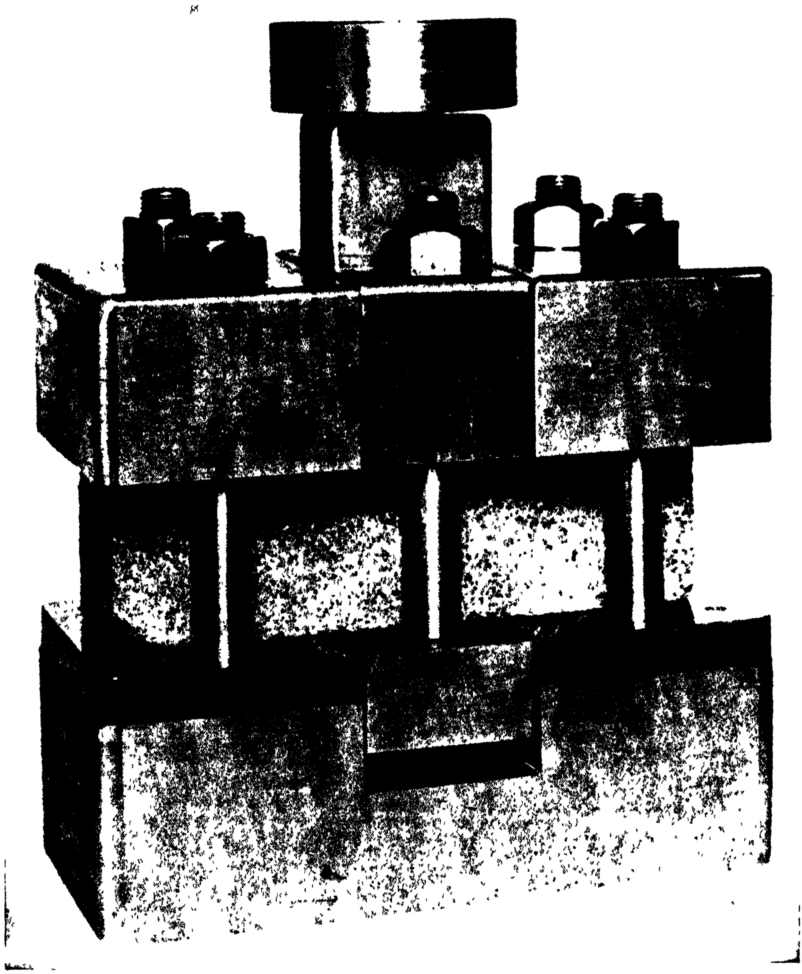

FIG. 8.—Shear tool with test piece mounted.

The mean values of the compressive strength for dry and wet rock are given in columns 9 and 10 respectively in pounds per square inch.

Shearing Strength

The shearing tool and the method used were in accordance with *A.S.T.M. Specification C. 102–36* on the shearing strength of natural stone. The modified Johnson shear tool described in this specification was constructed in the laboratory workshops.

The testing machine used for most of the tests was an Avery universal testing machine of 50,000 lb. capacity which could be mechanically operated at a constant speed of 0·05 in. per minute as laid down by the specification. A number of the tests were carried out on the laboratory's 10 ton Denison universal testing machine, which can be hand operated at about that speed. Both testing machines were checked—the Avery machine with a proving ring to full capacity, and the laboratory machine with dead weights to 4 tons and to 10 tons with a proving ring.

The shearing tool is illustrated in Fig. 8. The test piece of nominal dimensions 2 in. × 2 in. (shearing area) × 7 in. to 10 in. long is clamped firmly between the base and the two outer guide blocks by means of the four bolts. The central portion of the test specimen is clamped between the upper and lower parts of the moving jaw which transmits the shear.

The shearing tool has its own spherical seating device through a $\frac{5}{8}$ in. steel ball-bearing at the top of the moving block.

The ultimate procedure adopted was to clamp the specimen towards one end and to test it in double shear. The other portion was then similarly tested in double shear, and occasionally this could be done a third time. The broken portions were then tested in single shear, care being taken to ensure that the specimen projected at least two-thirds of the distance into the middle and side jaws respectively.

This equipment showed one rather serious disadvantage. Owing to the flexibility of the stone and the rather large clearance necessary between the bottom of the moving jaw and the hardened edges of the recessed portion of the base, flexing of the stone occurred with increasing load, causing the central moving jaw to be forced against one or other of the guides, the $\frac{5}{8}$ in. bolts of which underwent slight flexure. A steel girdle was constructed and mounted round the upper portion after the test piece had been positioned. The nuts were then tightened so that they just gripped. This reduced the tendency for the guiding blocks to spread, and assisted in keeping the shearing force in its correct alignment.

Columns 12 and 13 set out the estimated mean shearing strengths of the wet and dry samples respectively, calculated from all the tests made. The notation x/y means that from x test pieces, y tests were made in all—*i.e.*, 2/7 indicates that 7 shearing tests were made upon 2 test pieces.

Column 14: In view of the difficulty experienced with the shearing tool stated above, and the fact that this cannot be entirely obviated, it is probable that some of the large variations obtained on individual test pieces tested several times (frequently as much as $\pm$ 20 per cent. of the mean, and occasionally as much as $\pm$ 50 per cent.) were mainly due to difficulties in technique. It may be due to overstressing the stone throughout in one test, resulting in lower test values in subsequent specimens, but very few specimens showed this effect—many showed their highest results in fourth or fifth re-test. An examination of the broken portions did not reveal any natural causes for the low values except in isolated cases which were noted. It may be argued, therefore, that, as small test pieces tested similarly several times throughout their lengths in shear should show little variation, except where occasional large inclusions are sheared, the highest value of a set of tests on any test piece is probably nearest to the true shearing strength of that material. Giving this consideration, a maximum shearing strength is shown in column 14, which is the mean of the highest values obtained in testing the individual specimens. It is suggested that the true shearing strength lies between the mean overall value and the mean of the maximum values.

Here, again, no consistent variation was found when the specimen faces marked "Top" were oriented in different directions relative to direction of the shearing force.

Young's Modulus of Elasticity in Compression, and Poisson's Ratio

The testing procedure and equipment have largely been based on *A.S.T.M. Specification C. 100–36.* The compressometer was constructed

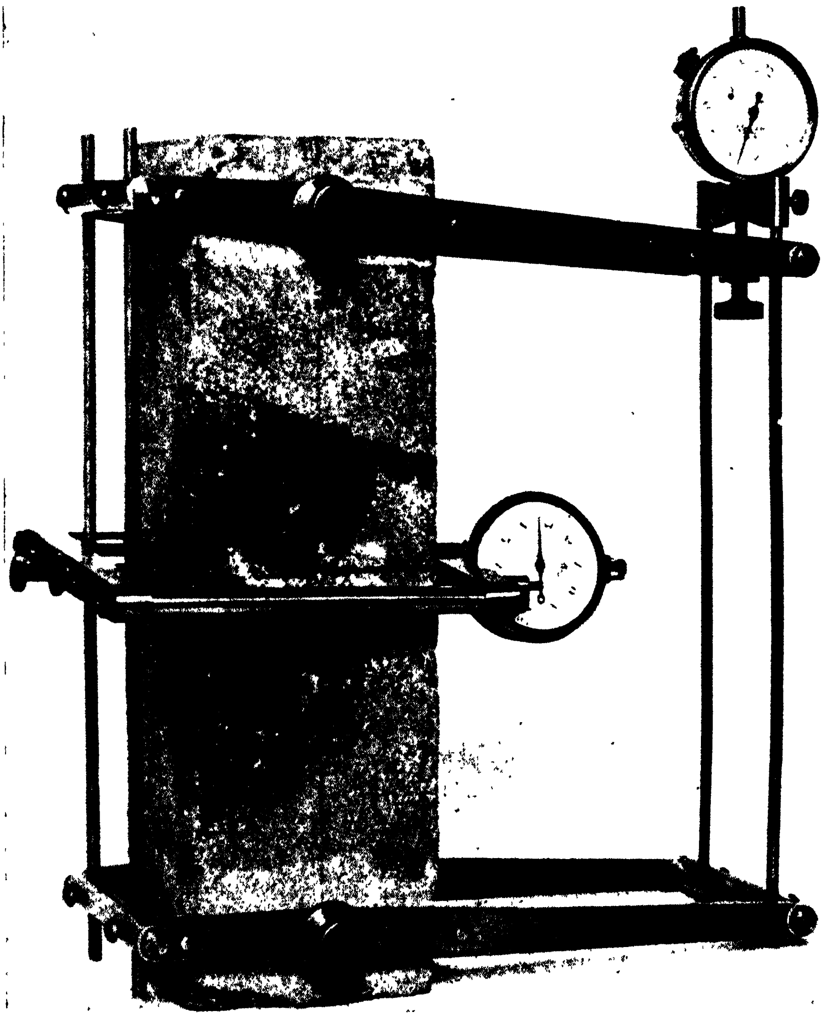

FIG. 9.—Compressometer and lateral extensometer mounted on test block.

in the workshop. In order to find Poisson's Ratio, a lateral extensometer was also designed and constructed for measuring the lateral extension across the mid-section of the test block at the same time as the contraction was being measured. Both pieces of equipment are illustrated in Fig. 9.

The test specimens were mostly of nominal dimensions, 12 in. × 3½ in. × 3½ in. The compressometer, which consists essentially of a lever and dial gauge, was clamped by means of the hardened screws to two points 10 in. apart on the test block. At the same time the lateral extensometer was attached to the mid-section of the test specimen. The block was then placed centrally on a spherical seating and the whole located centrally on the table of the Denison 10 ton universal testing machine. Sheet lead was placed between the end bearing faces of the test block and the surfaces of the testing machine and spherical seating.

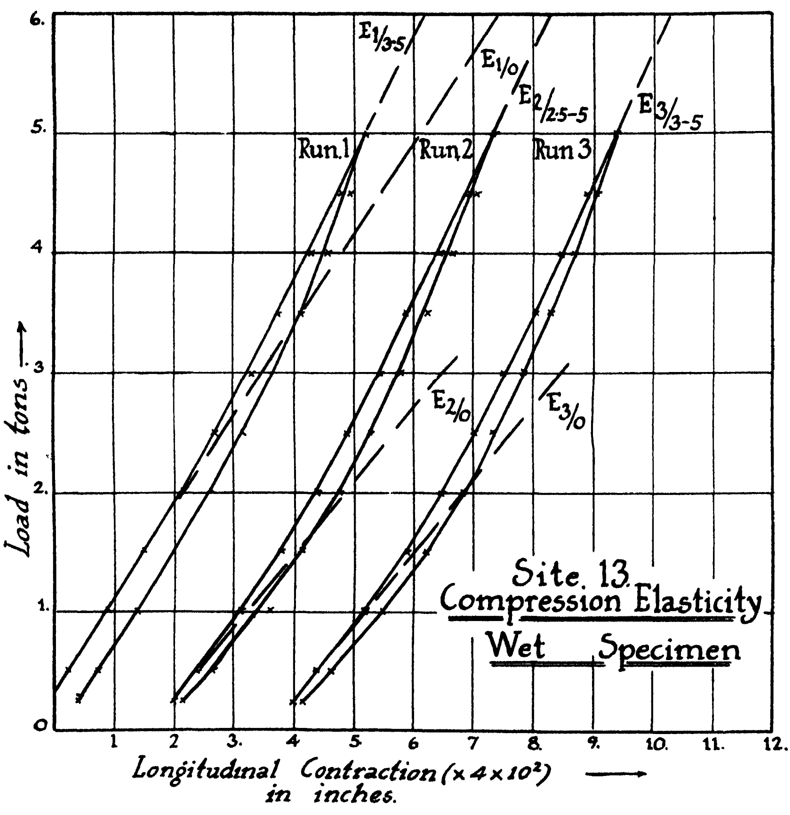

FIG. 10 (*a*).—Typical curves obtained in the test for elasticity in compression.

A load of 0·25 ton was applied to the test block for approximately one minute, and the dial gauges on the compressometer and lateral extensometer were set to zero and adjusted so that both could work to almost maximum range. The load was then steadily increased so that the rate of motion of the upper crosshead was approximately 0·03 in. per minute—less than 0·05 in. per minute—until 1 ton was applied. The two measuring instruments were then vibrated by means of two small electric buzzers, one of which was attached to each instrument; this assisted in removing the effect of friction in the moving parts of the equipment. The two dial gauges were then read. Increments of 0·5 ton were applied similarly for periods of approximately one minute until a maximum of 5 tons to 8 tons was applied, depending upon the crushing strength of the stone.

The load was then removed by ½ ton increments till 0·25 ton was left, the dial gauge readings again being recorded at each load. The load was next entirely removed for about ten minutes, and 0·25 ton again applied without removing the test block. The dial gauges were set to zero again, and the above procedure was repeated.

After this second "run," the two instruments were removed and fixed to the adjacent faces at right angles to the ones to which they were initially attached. The test was then carried out as before a third time. Graphs were plotted for each block: (1) load *v.* contraction, and (2) lateral strain *v.* longitudinal strain (see Figs. 10 (*a*) and 10 (*b*)).

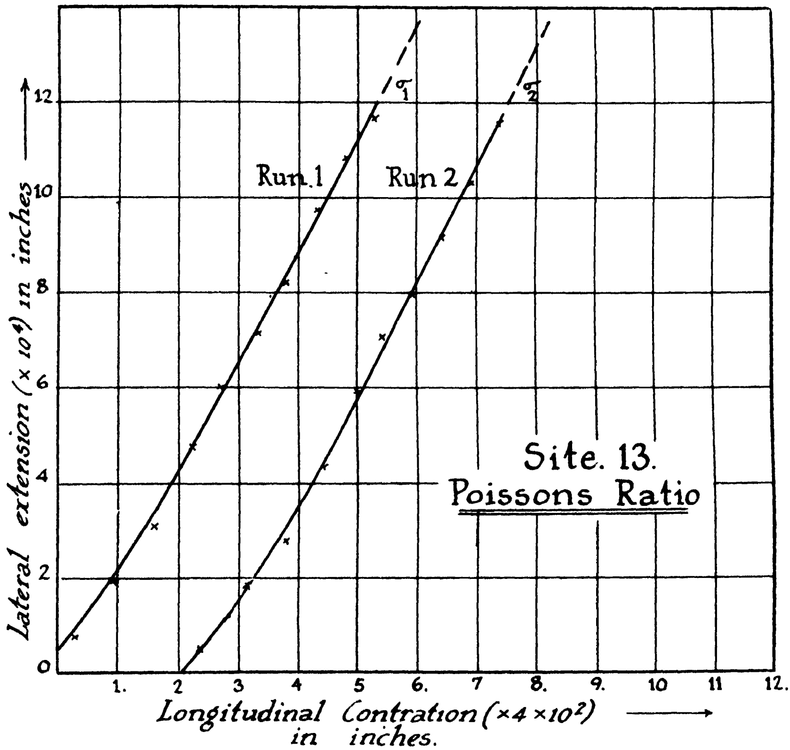

FIG. 10 (*b*).—Typical curves obtained in the test for elasticity in compression.

Two values of Young's modulus of elasticity were obtained for each "run," one approximating to that at zero strain—this was determined by drawing a straight line through the points of intersection of the curve with the 0·25 ton and 1 ton ordinates. A higher value for the modulus of elasticity was obtained by drawing a straight line through the upper portion of the curve, which tended to become linear.

The values of E were calculated by measuring the angles of these lines on the graphs, noting the dimensions of the test piece, and using a nomogram specially constructed. Column 18 of the data table gives the value of E at zero strain (secant 0·25 to 1·0 ton) for the dry stone during its initial test; column 20 gives E of a wet block from the same site during its initial run over a range of higher stress values (up to about half its breaking

stress). Column 22 shows the zero strain value for E of the same test piece for the second and third runs, which, in general, gave very similar curves, while column 24 gives the value of E for the second and third runs over the higher stress range (refer to Fig. 10 (*a*)).

Similarly, columns 19 and 21 refer to the values of E for wet stone at low and high stresses applied for the first time, while columns 23 and 25 give corresponding values for E for the wet stone during subsequent applications of stress. They are in most cases the mean values of two or more specimens.

Poisson's Ratio, by definition $= \frac{\text{Lateral strain}}{\text{Longitudinal strain.}}$ This was evidently changing with increase of stress set up in the blocks. Graphs were drawn, plotting lateral strain *v.* longitudinal strain, and values of these were selected from the straight portion of the curve so that the ratio could be determined (see Fig. 10 (*b*)).

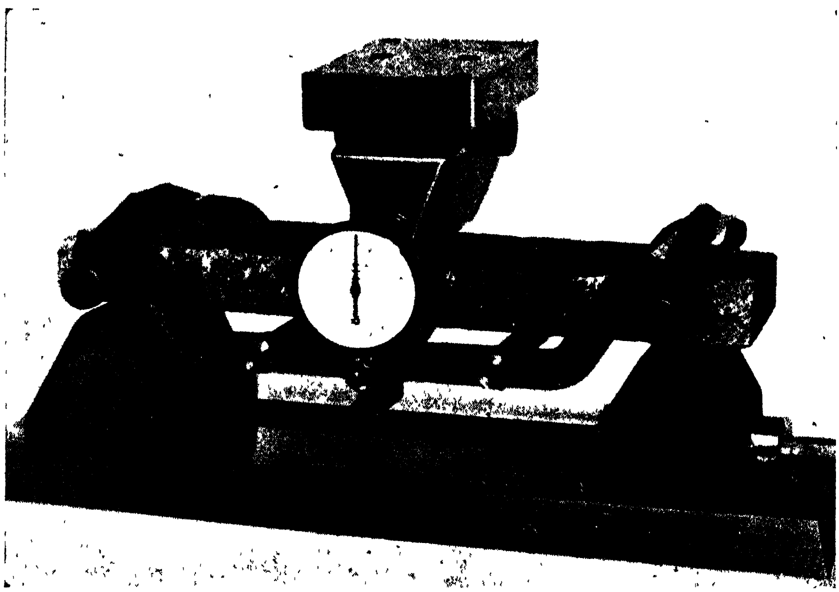

FIG. 11.—Deflectometer mounted on specimen.

The weakness in the testing procedure lay in the fact that longitudinal strain could be reasonably accurately measured as the gauge length was 10 in., and a mechanical lever system of 4 : 1 permitted measurements to be made to the order of 1/40,000 in. The lateral extensometer, however, was recording very much smaller strains over a length of only 3½ in. without any mechanical or optical magnification. The general indication, however, was that Poisson's Ratio was probably between 0·15 and 0·30.

Modulus of Elasticity in Flexure, and Modulus of Rupture

The equipment and test procedure were based on *A.S.T.M. C. 100–36*, and the deflectometer was constructed upon *A.S.T.M.* design in the engineering workshops. It is illustrated in Fig. 11.

The main feature is that one of the base supports can rotate in such a way as to be automatically self-aligning with the other support. The loading bearer is similarly self-aligning.

The test specimens are nominally 12 in. × 4 in. × 1 in. The cradle of the deflectometer is supported on two brackets which are clamped to the long 1 in. edges of the stone 10 in. apart. An inverted bracket is fixed to the mid-point of the stone—all points of attachment being along the neutral surface of the test piece. The stone slab is then placed across the self-aligning supports so that the span is 10 in. apart, the brackets being directly above the supports as in the illustration. A slight rotation of the middle inverted bracket will cause the dial gauge in contact with the bearing surface of the bracket to register an increase in reading and then a

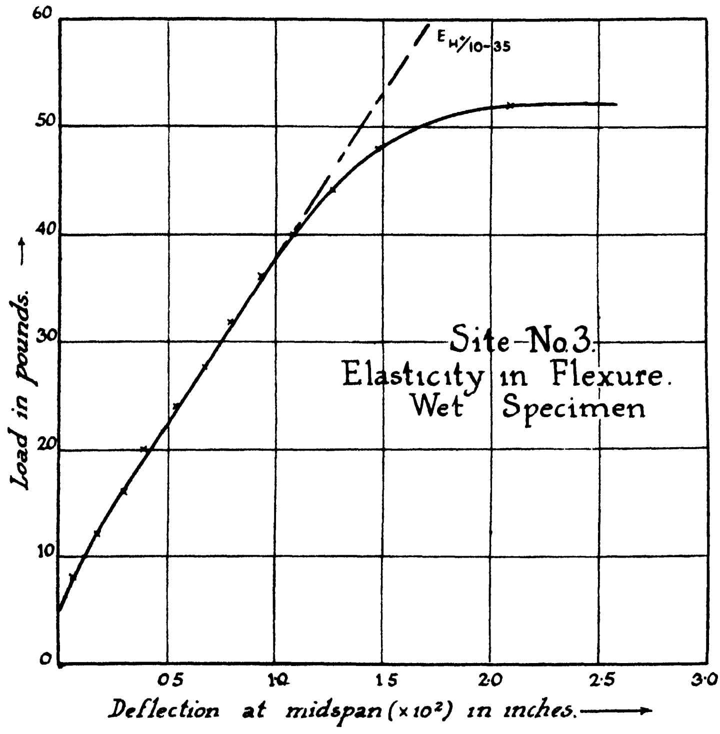

FIG. 12.—Flexural elasticity curve.

decrease. The middle bracket should be adjusted to the maximum reading, which means that the bearing surface is at right angles to the axis of the dial gauge shaft.

The deflectometer was mounted on the frame of the testing machine, which consisted esentially of a 2 : 1 lever. The load was transmitted from the lever vertically downwards on to the stone through a stirrup attached to the loading bearer. Fine lead shot running uniformly into a container at the free end of the lever applied the load, which could be measured accurately to ± ·2 oz. In order not to disturb the load being applied to the stone, the shot was weighed by registering the decrease in weight of a container from which the shot flowed into the loading can. This weight was doubled at the loading point of the lever.

The initial load applied mid-span to the stone was 12 lb., the weight of the stirrup and loading bearer. The dial gauge, reading in 1/10,000 in., was set to zero. Increments of 10 lb. load, approximately, were applied and the corresponding deflections observed on the dial gauge. This intermittent loading was continued till the specimen failed, the equipment being set up to prevent the loading head from falling after the stone broke.

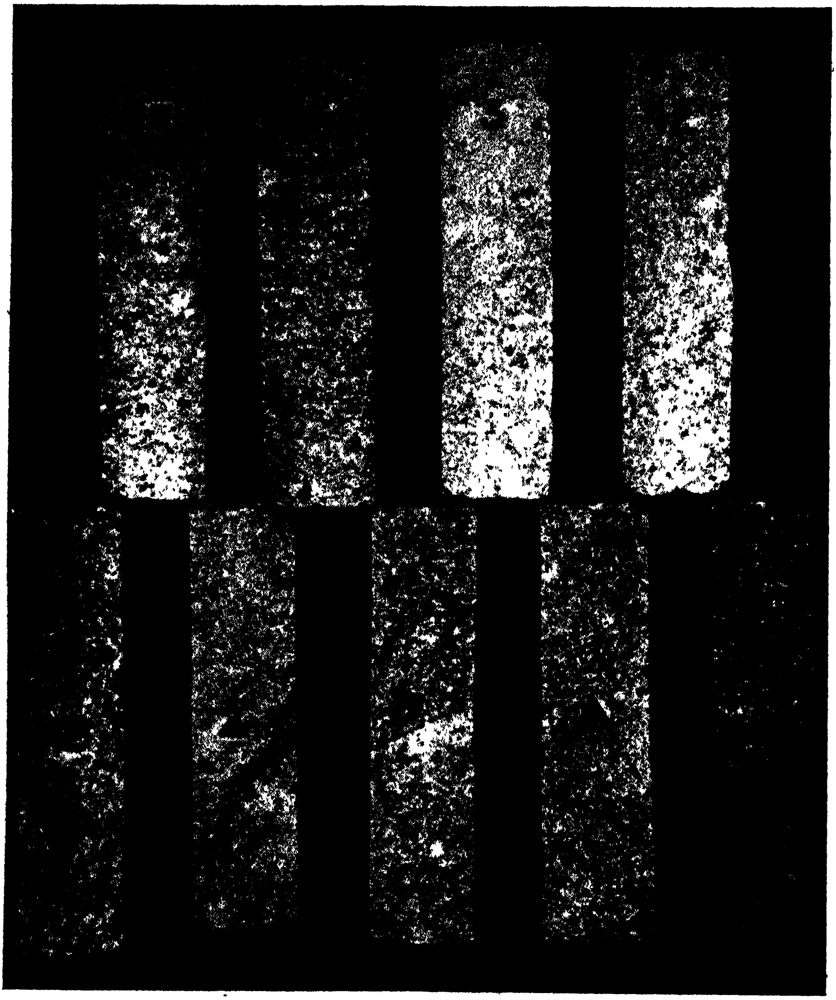

FIG. 13.—Broken flexural specimens with site numbers shown.

The load $v.$ deflection curve was plotted, and from this graph the value of the modulus of elasticity in flexure at varying stresses in the stone was obtained (1) by drawing the tangent at the zero deflection point on the graph and (2) a mean value over approximately half the breaking load by drawing a secant from zero deflection point to this half breaking load or along the initial straight portion of the graph (see Figs. 12 and 13).

It was found in practice that (1) was difficult to obtain accurately, so that only (2) was calculated from the graphs.

Columns 26 and 28 give the above values of E respectively for dry stone where they have been determined, and columns 27 and 29 the corresponding values for wet stone.

Modulus of Rupture

Values for this modulus were calculated using a breaking load of the stone obtained from the elasticity test above. It was considered that intermittent loading would result in " creep " taking place while the loads were held constant during the measurements of deflection, resulting in a breaking load lower than would occur with continuous loading. There were insufficient specimens available to obtain a modulus of rupture by continuous loading, so that columns 15 and 16 set out what may be regarded as the lower limit of this modulus for dry and wet stone respectively.

A number of broken portions from the elasticity tests were retested on a 4 in. span, using the deflectometer base without the cradle supporting the gauge, and the moduli of rupture calculated. These values are shown in column 17.

IV. NOTES ON THE RESULTS

It will be convenient to refer to Fig. 14, which shows the variation of most of the physical properties measured (on the wet stone especially) with the depth of the stone. On the horizontal scale the sites are set out in order of depth as one descends shaft 7 of the left bank (facing down stream), crosses the river, and then ascends the right bank.

On this chart, sites 1–4 and 39–42 lie in the middle sheet (see P.W.D. drawing EHN 1098/5), the upper sheet having been already weathered away, sites 5–49 on the left bank and 47–38 on the right being in the lower sheet.

The difference in the properties of the rock of these two sheets is strikingly demonstrated in the chart.

Although consecutive points have been joined by straight lines to facilitate the following of the changes that occur in the properties of the rock, the chart may be misleading unless it is borne in mind that these points do not always represent neighbouring sampling sites—*e.g.*, sites 9 and A are not neighbours, although approximately on the same level. Sites 18 and 48 are on different levels and far apart horizontally, hence the marked difference in their properties. Site 47 is about 15 ft. lower than site 20 and farther from the river—here the difference in strength properties is consistently shown in the chart.

Before discussing further the relative values at different sites, a brief reference to the probable accuracy of the results will be made.

Specific Gravity

This may be taken as being probably correct to 1 per cent. The order of accuracy of the weighings (assuming absolute dryness or complete saturation) varies from 1 in 500 for small blocks to 1 in 2,000 for large ones. That for linear measurements varies from 1 in 120 to 1 in 500. The graph indicates that the S.G. of the dry stone follows its depth with a reasonable expectation.

The upper (middle) sheet is distinctly lighter than the lower one, the first having specific gravities ranging from 1·76 to 1·90 for dry stone and 2·04 to 2·12 for wet; the lower sheet varies from 2·02 to 2·16 for dry stone and from 2·17 to 2·31 for wet.

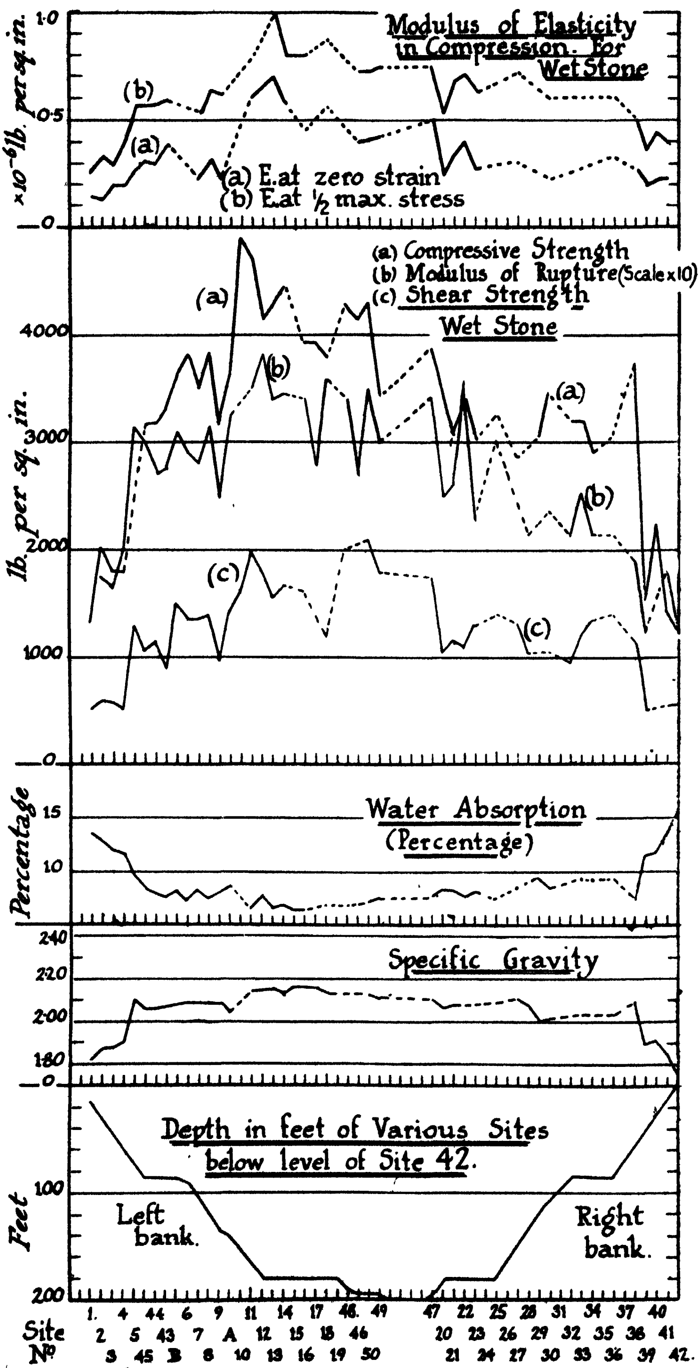

FIG. 14.—Chart showing variation of physical properties of the stone with depth.

Water Absorption and Resulting Expansion

The water absorption figures are probably too low by about 5 per cent. to 13 per cent. of the mean values tabulated. The material of the upper (middle) sheet varies from about 11·4 per cent. to 15·6 per cent. in this property to about from 6·5 per cent. to 10 per cent. for the lower sheet, based on the dry weight.

A further set of tests was made upon about thirty blocks (12 in. × 3½ in. × 3½ in.) which were oven dried for three days, weighed, and then placed in a large strong steel tank which was then closed and made airtight. The tank was evacuated and held at a vacuum of 26 in. of mercury for twenty-four hours. Water was permitted to enter the evacuated tank until the stone was totally immersed—this could be seen by means of a window in the tank. After twenty-four hours' immersion the blocks were reweighed. An increase varying from zero to 18 per cent. on the absorption measured by the previous method was recorded. The lowest sites showed the least differences. Figure 3 illustrates the rate of expansion with time of immersion.

Water Permeability

With one or two exceptions these values have proved consistent with the depth, S.G., and other properties of the rock. The material is very permeable compared with most stone, but the flow is given in cubic feet per square foot through a distance of 3 in. only. The data supplied for water permeability are probably correct to about ± 10 per cent. of the true permeability under the same conditions of test.

Compressive Strength

Preliminary tests showed that the use of sheet lead between the load-bearing faces of the test blocks did not significantly alter the crushing strength values from the values obtained by capping similar blocks with a strong cap of sulphur and sand. The latter method was discarded on account of the inconvenience and time factor for the large number of tests carried out. The comparisons above were made on relatively few samples—about ten of each—but if any error exists it will be on the safe side. Lead sheet will tend to give low values, as it has not the binding action on the specimen that a plaster or sulphur-sand cap would have on the ends of the test blocks. Definite and consistent differences have been found in this respect in tests of concrete blocks. Further work is being done to investigate the effect of capping with plaster of paris as for concrete testing.

The crushing strength of the lower sheet is reasonably high, ranging from about 3,000 lb. per square inch to about 4,300 lb. per square inch for wet stone—neglecting some extreme values. The upper sheet shows corresponding values of about 1,200 lb. to 2,200 lb. per square inch.

An analysis of the individual results for wet crushing strength shows that 80 per cent. were within ± 20 per cent. of the means shown in column 11 ; about 10 per cent. were more than 20 per cent. below the means tabulated.

It was not always possible to locate fine cracks even with a high-powered binocular microscope. and on occasions blocks which had apparent surface cracks gave high test values. Notwithstanding individual variations, Fig. 14 shows marked relationship between the depth and the strength of the rock at various places. The left bank (facing down stream) appears to be markedly stronger than the right bank.

Shear Strength

This has been fairly completely discussed in the account of testing procedure. It is sufficient to state that the variation in shearing strength follows that for compressive strength from site to site remarkably closely.

This rock has a high shearing strength compared with its compressive strength. The ratio shear strength : compressive strength varies from about 1 : 3·5 to 1 : 2·5. Data obtained from "Johnson's Materials of Construction" for the same ratio for a large variety of rock are mostly of the order of 1 : 5 to 1 : 15.

The shearing strength of the upper sheet ranges from about 400 lb. to 600 lb. per square inch for wet stone, and the lower from 1,300 lb. to 2,000 lb. per square inch.

Modulus of Rupture

As previously stated, this value will probably be somewhat lower than if it were carried out by continuous loading. The variation of the value from site to site follows the variation of compressive and shear strengths closely.

The upper sheet values range from 125 lb. to 180 lb. per square inch, and for the lower sheet from 250 lb. to 350 lb. per square inch. Data from "Johnson's Materials of Construction" seem to indicate that, in general, stone has a tensile strength of about half its modulus of rupture.

Elastic Moduli

Elasticity in Compression.—The value of E in compression for any specimen varies throughout the test, and is least at low stresses and rapidly increases to a constant value at stresses of about half the ultimate crushing strength of the stone or over.

The difficulty of assessing E was twofold :—

(1) Drawing the tangents correctly. Small angular variations when measuring angles of 60° or more produce much greater relative variations in the tangents and therefore in the value of E.

(2) It was originally intended to carry out this test to a maximum stress of about 1,500 lb. to 1,800 lb. per square inch. One or two blocks failed by splitting during the tests (the length : width ratio was about 3·5 : 1), so that the maximum working stresses were reduced to about 1,000 lb. per square inch. This tended to give a curve having a less steep slope than at higher loads.

For these reasons it would not be safe to assess the accuracy of these values closer than about $\pm$ 20 per cent.

The form of the curve of modulus of elasticity in compression is rather to be expected from a material which, though strong in crushing and shear strengths, is light and highly porous. It appears evident that increased loading causes compaction of the material, with a fair amount of permanent set, as is shown by the decrement curves in Fig. 8.

Elasticity in Flexure.—This value of E is considerably lower than that obtained for compression—it tends to approach the value of E in compression when the compressive stress in the block is zero. The curve shows a maximum value at zero stress.

This, together with the low modulus of rupture, seems to suggest that the ignimbrite is "strongly welded" in that its shearing resistance is high,

but that it lacks in tensile strength. The large deflection in the flexural test could be accounted for by the fact that considerable compaction takes place at low stresses on the compression side of the bend, while the material has not the property of offering much resistance to tensile strain on the opposite side of the bend.

Probably the mean value of E—*i.e.*, not at zero strain—is accurate to within $\pm$ 10 per cent., as the curve is linear over the mean portion of its stress range.

Suggestions as to dividing the Site into Zones with Uniform Properties

Zone 1 : Sites 1–4 inclusive :—

Compressive strength (C.S.) .. .. = 1,700 lb./sq. in.
Shear strength (S.S.) .. .. .. = 600 lb./sq. in.
Modulus of rupture (M.R.) .. .. = 175 lb./sq. in.
Modulus of elasticity in compression (E_c) .. = $0{\cdot}15 \times 10^6 - 0{\cdot}35 \times 10^6$ lb./sq. in.
Modulus of elasticity in flexure (E_f) .. = $0{\cdot}15 \times 10^6$ lb./sq. in.

Zone 2 : Sites 5–8 inclusive :—
C.S. = 3,600 lb./sq. in.
S.S. = 1,350 lb./sq. in.
M.R. = 300 lb./sq. in.
E_c = $0{\cdot}23 - 0{\cdot}6 \times 10^6$ lb./sq. in.
E_f = $0{\cdot}18 \times 10^6$ lb./sq. in.

Zone 3 : Sites 43–45 and B :—
C.S. = 3,200 lb./sq. in.
S.S. = 1,100 lb./sq. in.
M.R. = 280 lb./sq. in.
E_c = $0{\cdot}3 - 0{\cdot}58 \times 10^6$ lb./sq. in.
E_f = $0{\cdot}2 \times 10^6$ lb./sq. in.

Zone 4 : Site 9.—A sudden marked reduction occurs at this site. It is not clear whether the samples submitted had been damaged through blasting or whether the reduced values are due to natural causes—*e.g.*, pressure joint.
C.S. = 3,100 lb./sq. in.
S.S. = 1,100 lb./sq. in.
E_c = $0{\cdot}22 - 0{\cdot}6 \times 10^6$ lb./sq. in.
E_f = $0{\cdot}16 \times 10^6$ lb./sq. in.

Zone 5 : Sites 10–12 inclusive :—
C.S. = 4,500 lb./sq. in.
S.S. = 1,800 lb./sq. in.
M.R. = 350 lb./sq. in.
E_c = $0{\cdot}6 - 1{\cdot}0 \times 10^6$ lb./sq. in.
E_f = $0{\cdot}24 \times 10^6$ lb./sq. in.

Zone 6 : Sites 13–19 inclusive :—
C.S. = 4,000 lb./sq. in.
S.S. = 1,600 lb./sq. in.
M.R. = 320 lb./sq. in.
E_c = $0{\cdot}5 - 0{\cdot}8 \times 10^6$ lb./sq. in.
E_f = $0{\cdot}25 \times 10^6$ (variable) lb./sq. in.

Zone 7 : Sites 48, 46, 50 :—
C.S. = 4,200 lb./sq. in.
S.S. = 2,000 lb./sq. in.
M.R. = 340 lb./sq. in.
E_c = $0{\cdot}4 - 0{\cdot}7 \times 10^6$ lb./sq. in.
E_f = $0{\cdot}22 \times 10^6$ lb./sq. in.

Zone 8 : Site 49 :—
C.S. = 3,400 lb./sq. in.
S.S. = 1,800 lb./sq. in.
M.R. = 300 lb./sq. in.
E_c = $0{\cdot}4 - 0{\cdot}7 \times 10^6$ lb./sq. in.
E_f = $0{\cdot}22 \times 10^6$ lb./sq. in.

Zone 9 : Site 47 :—
C.S. = 3,800 lb./sq. in.
S.S. = 1,750 lb./sq. in.
M.R. = 350 lb./sq. in.
E_c = $0{\cdot}5 - 0{\cdot}75 \times 10^6$ lb./sq. in.
E_f = $0{\cdot}3 \times 10^6$ lb./sq. in.

Zone 10 : Sites 20–25 inclusive :
C.S. = 3,200 lb./sq. in.
S.S. = 1,200 lb./sq. in.
M.R. = 250 lb./sq. in.
E_c = $0{\cdot}3 - 0{\cdot}68 \times 10^6$ lb./sq. in.
E_f = $0{\cdot}2 \times 10^6$ lb./sq. in.
Site 22 seems somewhat higher in the above properties.

Zone 11 : Sites 26–30 inclusive :—
C.S. = 3,000 lb./sq. in.
S.S. = 1,100 lb./sq. in.
M.R. = 220 lb./sq. in.
E_c = $0{\cdot}25 - 0{\cdot}65 \times 10^6$ lb./sq. in.
E_f = $0{\cdot}16 \times 10^6$ lb./sq. in.

Zone 12 : Sites 31–36 inclusive :—
C.S. = 3,100 lb./sq. in.
S.S. = 1,200 lb./sq. in.
M.R. = 220 lb./sq. in.
E_c = $0{\cdot}25 - 0{\cdot}61 \times 10^6$ lb./sq. in.
E_f = $0{\cdot}15 \times 10^6$ lb./sq. in.

Zone 13 : Sites 38–42 inclusive :—
C.S. = 1,500 lb./sq. in.
S.S. = 550 lb./sq. in.
M.R. = 150 lb./sq. in.
E_c = $0{\cdot}22 - 0{\cdot}4 \times 10^6$ lb./sq. in.
E_f = $0{\cdot}1 \times 10^6$ lb./sq. in.

Formulae used in Calculations

(1) Specific gravity .. .. $= \dfrac{\text{Weight of block in pounds} \times 1{,}728}{\text{Volume of block in cubic inches} \times 62{\cdot}5.}$

(2) Water absorption (percentage).. $= \dfrac{W_2 - W_1}{W_1} \times \dfrac{100.}{1}$ W_1 = weight of dry block; W_2 = weight of wet block.

(3) Water permeability (cu. ft./sec./sq. ft.) $= \dfrac{\text{Flow in pints observed}}{\text{Time in seconds} \times 50} \times \dfrac{144,}{25}$ since 1 cubic foot = 50 pints.

(4) Compressive strength (lb./sq. in.) $= \dfrac{\text{Ultimate load in tons} \times 2{,}240}{\text{Area of cross section of block in square inches.}}$

(5) Shearing strength (lb./sq. in.) .. $= \dfrac{\text{Ultimate shearing load in pounds}}{\text{Total area under shear in square inches.}}$

(6) Modulus of rupture .. .. $= \dfrac{3\,Wl}{2\,bd^2}$

where W = breaking load in pounds at mid span.
l = span in inches (mostly 10 in.).
b = breadth of block (nominally 4 in.).
d = depth of block (nominally 1 in.).

(7) Modulus of elasticity in compression (lb./sq. in.) $= \dfrac{\text{Compressive stress}}{\text{Compressive strain}}$

$= \dfrac{W}{A} \times \dfrac{L}{c}$

where W = load increment in pounds causing a contraction c in. from graph.
L = gauge length of blocks (nominally 10 in.).
A = cross-sectional area in square inches.

(8) Modulus of elasticity in flexure (lb./sq. in.) $= \dfrac{Wl^3}{4\,bd^3D}$

where W = load in pounds at mid span producing a deflection D in.
b = width of specimen (nominally 4 in.).
d = depth of specimen (nominally 1 in.).
l = span of specimen (nominally 10 in.).

Formulæ 5, 6, 7, and 8, however, were not used, but the calculations made by nomograms specially prepared from the above formulæ. All calculations made by one worker were checked independently by another.

In the table of results it will be observed that large gaps occur in some of the tests, especially with respect to water permeability and modulus of rupture. The main emphasis was given to values for wet stone, as this proved to be weaker. Further, practical considerations did not permit of more samples being obtained to give a comprehensive set of tests on every site.

When this became obvious, particular attention was given to certain tests in alternate sites and the remaining tests on the intermediate sites—*i.e.*, it was more economical to subject, say, sites 20, 22, 24, and 26 to three or four types of test and 21, 23, 25, 27, &c., to the remaining tests. Water permeability measurements ran over periods of two to four days, necessitating fewer samples selected over a wide range of sites.

SUMMARY OF MEAN VALUES OF PHYSICAL PROPERTIES OF MARAETAI STONE

NOTES.—(1) Figures in parentheses ( ) indicate the number of tests carried out; (2) figures set out as $^3/_7$: see text under "Shearing Test."

Site No.	Depth below Reference Level (Feet).	Specific Gravity.		Water Absorption on Dry Weight (Percentage).	Water Permeability.			Cœfficient of Expansion due to Water Absorption (× 10⁴).	Compressive Strength (lb./sq. in.).		Shearing Strength (lb./sq. in.).		
					Working Pressure (lb./sq. in.).	Flow, in cu. ft./sec./sq. ft. (× 10⁴).					Mean of all Tests.		Maximum Values of Specimens.
		Dry.	Wet.			Under Working Pressure.	Under 150 lb./sq. in.		Dry.	Wet.	Dry.	Wet.	
1.*	2.	3.	4.	5.	6.	7.	8.	9.	10.	11.	12.	13.	14.
1	15	1·83($_6$)	..	13·5($_5$)	6·5	Nil	8·55	3·8–4·7	2,610($_5$)	..	$710^2/_2$	..	715
		..	2·09($_{17}$)	..	..	..	..	4·1($_3$)	..	1,320($_4$)	..	$650^2/_3$	800
2	30	1·87	..	12·5($_4$)	..	..	..	2·0–4·3	2,840($_1$)	..	$730^1/_4$	..	800
		..	2·10($_9$)	..	..	..	..	2·9($_3$)	..	2,030($_4$)	..	$600^3/_{16}$	720
3	45	1·88($_3$)	..	12·0($_4$)	19·8	0·128	2·68	3·0–3·1	..	..	$600^1/_4$	..	700
		..	2·11($_{11}$)	..	..	..	..	3·1($_2$)	..	1,800($_8$)	..	$570^6/_{38}$	690
4	60	1·90($_{14}$)	..	11·7($_3$)	26·0	0·79	6·45	3·3–3·7	2,770($_3$)	..	$650^3/_9$	..	720
		..	2·12($_{10}$)	..	..	0·95	7·75	3·5	..	1,790($_4$)	..	$500^2/_4$	500
5	75	2·10($_9$)	..	9·8($_1$)	..	..	..	1·32($_1$)	5,190($_3$)	..	$1,600^3/_9$	..	1,790
		..	2·25($_2$)	..	..	..	..	..	..	..	..	$1,300^3/_{15}$	1,560
6	90	2·09($_2$)	..	7·3($_1$)	..	..	..	..	..	..	..	..	..
		..	2·26($_4$)	..	..	..	..	..	..	3,800($_3$)	..	$1,300^2/_{10}$	1,430
7	105	2·09($_3$)	..	8·3($_2$)	45·5	0·16	0·67	..	4,240($_2$)	..	$1,500^1/_5$	..	1,630
		..	2·26($_9$)	..	..	..	..	..	..	3,500($_6$)	..	$1,350^5/_{25}$	1,510
8	120	2·09($_4$)	..	7·3($_1$)	..	..	..	1·8–2·2	5,070($_2$)	..	$1,600^1/_6$	..	1,870
		..	2·25($_8$)	..	..	..	..	2·0($_2$)	..	3,820($_6$)	..	$1,400^4/_{16}$	1,670
9	135	2·09($_9$)	..	8·1($_6$)	..	..	..	..	4,320($_8$)	..	$1,000^1/_3$	..	1,600
		..	2·26($_6$)	..	..	..	..	1·2	..	3,110($_4$)	..	$950^3/_{12}$	1,220

* Columns 15–29 on page 106.

SUMMARY OF MEAN VALUES OF PHYSICAL PROPERTIES OF MARAETAI STONE—*continued*

NOTES.—(1) Figures in parentheses ( ) indicate the number of tests carried out; (2) figures set out as $^{3}/_{7}$: see text under "Shearing Test."

Site No.	Depth below Reference Level (Feet).	Specific Gravity. Dry.	Specific Gravity. Wet.	Water Absorption on Dry Weight (Percentage).	Water Permeability. Working Pressure (lb./sq. in.).	Water Permeability. Flow, in cu. ft./sec./sq. ft. ($\times 10^4$). Under Working Pressure.	Water Permeability. Flow, in cu. ft./sec./sq. ft. ($\times 10^4$). Under 150 lb./sq. in.	Cœfficient of Expansion due to Water Absorption ($\times 10^4$).	Compressive Strength (lb./sq. in.). Dry.	Compressive Strength (lb./sq. in.). Wet.	Shearing Strength (lb./sq. in.). Mean of all Tests. Dry.	Shearing Strength (lb./sq. in.). Mean of all Tests. Wet.	Shearing Strength (lb./sq. in.). Maximum Values of Specimens.
1.	2.	3.	4.	5.	6.	7.	8.	9.	10.	11.	12.	13.	14.
10	150	..	..	..	..	..	..	..	..	..	$2{,}100^{2}/_{9}$	..	2,480
		..	2·30($_{4}$)	..	..	..	..	..	..	4,900($_{4}$)	..	$1{,}600^{3}/_{13}$	1,990
11	165	2·14($_{9}$)	..	6·8($_{3}$)	71·6	0·37	0·82	1·0–1·5	..	..	..	..	..
		..	2·30($_{6}$)	..	..	..	..	1·25($_{2}$)	..	4,800($_{4}$)	..	$2{,}000^{6}/_{31}$	2,330
12	180	2·15($_{11}$)	..	7·6($_{3}$)	..	..	..	0·7–0·9	3,990($_{2}$)	..	..	..	..
		..	2·29($_{3}$)	..	..	..	..	0·8($_{2}$)	..	4,110($_{2}$)	..	$1{,}800^{4}/_{21}$	1,970
13	180	2·15($_{15}$)	..	6·4($_{10}$)	78	0·75	1·49	0·8–2·1	5,800($_{7}$)	..	$1{,}600^{3}/_{14}$	..	2,230
		..	2·29($_{26}$)	..	..	..	..	1·5($_{8}$)	..	4,270($_{11}$)	..	$1{,}550^{8}/_{39}$	1,870
14	180	2·13($_{6}$)	..	6·9($_{14}$)	78	0·43	0·93	1·2–2·5	6,800($_{3}$)	..	$1{,}350^{2}/_{3}$	..	1,500
		..	2·30($_{8}$)	..	..	0·59	1·16	1·73($_{3}$)	..	4,450($_{6}$)	..	$1{,}700^{5}/_{24}$	2,000
15	180	2·16($_{6}$)	..	6·5($_{14}$)	..	..	..	..	5,700($_{6}$)	..	..	..	..
		..	2·30($_{9}$)	..	..	..	..	..	..	..	..	$1{,}550^{2}/_{8}$	1,900
16	180	2·16($_{14}$)	..	6·4($_{4}$)	..	..	..	0·3–1·3	5,080($_{5}$)	..	$1{,}650^{3}/_{7}$	..	1,720
		..	2·30($_{12}$)	..	..	..	..	0·7($_{4}$)	..	3,920($_{10}$)	..	$1{,}600^{3}/_{15}$	1,820
17	180	2·16($_{4}$)	..	..	78	0·69	1·54	..	5,980($_{4}$)	..	$1{,}700^{1}/_{1}$	..	1,710
		..	2·31($_{3}$)	..	..	..	..	..	..	3,920($_{4}$)	..	..	..
18	180	2·14($_{7}$)	..	6·9($_{2}$)	..	..	..	1·3–1·5	6,200($_{3}$)	..	$1{,}250^{2}/_{8}$	..	1,460
		..	2·29($_{6}$)	..	..	..	..	1·4($_{2}$)	..	3,800($_{7}$)	..	$1{,}200^{2}/_{8}$	1,320

19	No specimens received.												
20	180	2·06($_3$)	..	8·2($_2$)	..	..	..	1·7–2·8	4,200($_3$)	..	1,250$^2/_{10}$	..	1,520
		..	2·23($_5$)	..	..	..	..	2·2	..	3,460($_6$)	..	1,050$^5/_{28}$	1,200
21	180	2·08($_{24}$)	..	8·1($_9$)	78	1·02	1·96	1·1–2·1	4,420($_4$)	..	1,250$^6/_{18}$	..	1,370
		..	2·25($_{21}$)	..	..	..	..	1·4($_7$)	..	3,050($_{12}$)	..	1,150$^{11}/_{45}$	1,230
22	180	2·08($_{13}$)	..	7·6($_2$)	..	..	..	0·8–1·4	5,600($_4$)	..	1,200$^3/_{11}$	..	1,330
		..	2·25($_{18}$)	..	..	..	..	1·2($_4$)	..	3,400($_{13}$)	..	1,100$^8/_{26}$	1,140
23	180	2·08($_7$)	..	8·1($_4$)	78	0·67	1·37	1·3–1·6	4,560($_2$)	..	1,500$^1/_4$	..	1,840
		..	2·24($_{16}$)	..	..	0·92	1·75	1·5($_3$)	..	3,000($_{11}$)	..	1,300$^{12}/_{61}$	1,510
24	180	..	..	..	..	..	..	..	..	..	1,500$^1/_3$	..	1,480
		..	..	..	..	..	..	..	..	..	..	..	..
25	180	2·09($_8$)	..	7·6($_3$)	78	1·03	1·95	..	5,050($_5$)	..	1,300$^1/_1$	..	1,300
		..	2,26($_6$)	..	..	..	..	1·7($_1$)	..	3,250($_{11}$)	..	1,400$^2/_{11}$	1,520
26	No specimens received.												
27	150	2·11($_8$)	..	8·5($_3$)	..	..	..	..	4,800($_6$)	..	1,300$^2/_4$	..	1,350
		..	2·28($_3$)	..	..	..	..	..	..	2,830($_6$)	..	1,300$^4/_{13}$	1,470
28	135	2·08($_5$)	..	..	..	..	..	..	3,610($_1$)	..	1,050$^1/_3$	..	1,240
		..	..	..	..	..	..	..	..	..	..	1,050$^1/_6$	1,350
29	120	2·00($_5$)	..	9·4($_2$)	..	..	..	..	3,900($_4$)	..	1,030$^1/_1$	..	..
		..	2·17($_4$)	..	..	..	..	1·4($_1$)	..	3,050($_4$)	..	..	..
30	105	2·02($_4$)	..	8·4($_3$)	..	..	..	2·3–4·3	4,470($_3$)	..	1,250$^4/_4$	..	1,270
		..	2·19($_3$)	..	..	..	..	3·03($_3$)	..	3,480($_1$)	..	1,050$^4/_4$	1,050
31	No specimens received.												
32	85	..	..	..	..	..	..	..	4,500($_2$)	..	..	..	..
		..	2·19($_4$)	..	..	..	..	..	..	3,200($_6$)	..	950$^4/_{16}$	1,080

SUMMARY OF MEAN VALUES OF PHYSICAL PROPERTIES OF MARAETAI STONE—*continued*

NOTES.—(1) Figures in parentheses ( ) indicate the number of tests carried out ; (2) figures set out as $^{3}/_{7}$: see text under "Shearing Test."

Site No.	Depth below Reference Level (Feet).	Specific Gravity.		Water Absorption on Dry Weight (Percentage).	Water Permeability.			Cœfficient of Expansion due to Water Absorption (× 10⁴).	Compressive Strength (lb./sq. in.).		Shearing Strength (lb./sq. in.).		
		Dry.	Wet.		Working Pressure (lb./sq. in.).	Flow, in cu. ft./sec./sq. ft. (× 10⁴). Under Working Pressure.	Flow, in cu. ft./sec./sq. ft. (× 10⁴). Under 150 lb./sq. in.		Dry.	Wet.	Mean of all Tests. Dry.	Mean of all Tests. Wet.	Maximum Values of Specimens.
1.	2.	3.	4.	5.	6.	7.	8.	9.	10.	11.	12.	13.	14.
33	85	2·04($_{1}$)	..	9·2($_{1}$)	..	..	..	..	4,490($_{2}$)	..	..	..	..
		..	2·23($_{5}$)	..	..	..	..	1·5($_{1}$)	..	3,200($_{6}$)	..	$1{,}200^{4}/_{10}$	1,500
34	85	2·04($_{6}$)	..	9·1($_{1}$)	..	..	..	..	4,000($_{2}$)	..	$1{,}150^{2}/_{2}$	..	1,150
		..	2·21($_{2}$)	..	..	..	..	..	..	2,900($_{3}$)	..	$1{,}350^{6}/_{26}$	1,520
35	85	..	..	..	..	..	..	..	..	..	..	..	..
		..	2·19($_{3}$)	..	..	..	..	..	..	..	..	..	..
36	85	2·04($_{4}$)	..	9·2($_{3}$)	36·8	0·47	2·56	1·3–1·7	..	..	..	..	..
		..	2·23($_{7}$)	..	..	0·90	3·76	1·5($_{2}$)	..	3,070($_{8}$)	..	$1{,}400^{3}/_{16}$	1,590
37	No specimens received.												
38	60	2·10($_{3}$)	..	7·5($_{3}$)	..	..	..	1·1–1·3	2,400($_{1}$)	..	..	..	..
		..	2·25($_{5}$)	..	..	..	..	1·2($_{2}$)	..	3,750($_{2}$)	..	$1{,}150^{1}/_{6}$	1,280
39	45	1·90($_{7}$)	..	11·4($_{2}$)	..	..	..	1·7–2·7	2,050($_{5}$)	..	$500^{1}/_{4}$	..	620
		..	2·10($_{8}$)	..	..	..	..	2·4($_{3}$)	..	1,550($_{8}$)	..	$500^{5}/_{15}$	590
40	30	1·92($_{3}$)	..	11·9($_{3}$)	..	..	..	..	2,630($_{5}$)	..	$850^{2}/_{2}$	..	890
		..	2·18($_{4}$)	..	..	..	..	1·7($_{1}$)	..	2,260($_{1}$)	..	..	..
41	15	1·85($_{7}$)	..	13·4($_{4}$)	6·5	0·15	3·93	1·5–2·1	1,170($_{1}$)	..	$600^{2}/_{2}$	..	600
		..	2·06($_{12}$)	..	..	0·32	5·20	1·8($_{4}$)	..	1,460($_{3}$)	..	$550^{5}/_{16}$	580

42	0	1·76($_3$) ..	.. 2·04($_8$)	15·6($_3$) ..	.. ..	.. ..	.. ..	.. 3·8($_1$)	.. ..	.. 1,230($_8$)	.. ..	.. 550$^4/_{18}$	.. 650
43	85	2·07($_5$) ..	.. 2·23($_5$)	7·7($_5$) ..	.. ..	.. ..	.. ..	.. 1·6($_1$)	5,000($_4$) ..	.. 3,300($_5$)	.. ..	.. 880$^4/_{16}$	.. 1,100
44	85	2·06($_8$) ..	.. 2·24($_{14}$)	8·0($_4$) ..	36·8 ..	0·4 ..	2·0 ..	1·9–3·4 2·7($_3$)	3,860($_3$) ..	.. 3,180($_5$)	1,250$^1/_4$ ..	.. 1,150$^{11}/_{24}$	1,540 1,840
45	85	2·06($_1$) ..	.. 2·23($_4$)	8·2($_1$) ..	.. ..	.. ..	.. ..	.. ..	4,470($_3$) ..	.. 3,160($_4$)	.. ..	.. 1,080$^4/_{15}$	.. 1,310
46	195	.. ..	.. 2·27($_2$)	.. ..	.. ..	.. ..	.. ..	.. ..	.. ..	.. 4,145($_2$)	.. ..	.. ..	.. ..
47	195	2·10($_7$) ..	.. 2·26($_5$)	7·8($_2$) ..	84·7 ..	0·55 ..	0·96 ..	1·2–1·3 1·2($_3$)	.. ..	.. 3,890($_3$)	.. ..	.. 1,750$^5/_{25}$	.. 1,990
48	190	2·14($_5$) ..	.. 2·27($_9$)	6·9($_2$) ..	.. ..	.. ..	.. ..	.. ..	.. ..	.. 4,300($_5$)	.. ..	.. 2,000$^2/_{13}$	.. 2,480
49	195	2·11($_8$) ..	.. 2·27($_{11}$)	7·5($_4$) ..	84·7 ..	1·13 ..	2·0 ..	.. ..	.. ..	.. 3,420($_6$)	.. ..	.. 1,800$^5/_{32}$	.. 1,900
50	195	2·13($_6$) ..	.. 2·25($_8$)	7·1($_3$) ..	84·7 ..	0·43 ..	0·85 ..	.. ..	.. ..	.. 4,300($_3$)	.. ..	.. 2,100$^4/_{15}$	.. 2,400
A1	140	2·05($_6$) ..	.. 2·22($_8$)	8·7($_3$) ..	60·7 ..	0·64 0·49	2·11 1·36	.. ..	.. ..	.. 3,650($_3$)	.. ..	.. 1,450$^4/_{22}$	.. 1,610
A2	140	2·06($_6$) ..	.. 2·23($_4$)	8·7($_4$) ..	60·7 ..	0·68 ..	2·03 ..	.. ..	.. ..	.. 3,680($_5$)	.. ..	.. 1,450$^1/_4$	.. 1,590
B1	85	2·08($_7$) ..	.. 2·21($_9$)	8·2($_3$) ..	36·8 ..	0·19 ..	1·24 ..	.. ..	.. ..	.. 3,650($_4$)	.. ..	.. 1,500$^2/_{13}$	.. 1,820

SUMMARY OF MEAN VALUES OF PHYSICAL PROPERTIES OF MARAETAI STONE—*continued*

NOTES.—(1) Figures in parentheses ( ) indicate the number of tests carried out; (2) figures set out as $^3/_7$: see text under "Shearing Test."

Site No.	Modulus of Rupture (lb./sq. in.).			Young's Modulus of Elasticity in Compression (lb./sq. in. × 10⁻⁶).								Modulus of Elasticity in Flexure (lb./sq. in × 10⁻⁶).			
	Intermittent Load on 10 in. Span.		Continuous Loading on 4 in.	Initial Run.				Second and Third Runs.				At Zero Strain.		Mean to Half Maximum.	
				At Zero Strain.		Mean to Half Maximum.		At Zero Strain.		Mean to Half Maximum.					
	Dry.	Wet.		Dry.	Wet.	Dry.	Wet.	Dry.	Wet.	Dry.	Wet.	Dry.	Wet.	Dry.	Wet.
	15.	16.	17.	18.	19.	20.	21.	22.	23.	24.	25.	26.	27.	28.	29.
1	160(4)	..	..	0·17	..	0·26	..	0·16	..	0·34(3)	..	0·27(1)	..	0·14(4)	..
	..	..	..	..	0·13	..	0·22	..	0·14	..	0·25(3)	..	..	..	..
2	..	..	..	0·26	..	0·32	..	0·325	..	0·44(3)	..	..	..	..	..
	..	175(2)	..	..	0·08	..	0·23	..	0·12	..	0·33(1)	..	..	..	0·12(2)
3	133(1)	..	..	0·32	..	0·36	..	0·33	..	0·41(3)	..	..	..	0·16(1)	..
	..	165(5)	200(4)	..	0·12	..	0·30	..	0·19	..	0·33(1)	..	..	..	0·16(4)
4	315(1)	..	..	0·38	..	0·41	..	0·36	..	0·52(3)	..	..	..	0·29(1)	..
	..	200(1)	..	..	0·24(2)	..	0·40(2)	..	0·19	..	0·40(1)	..	..	..	0·18(1)
5	..	..	..	0·51	..	0·60	..	0·41	..	0·78(2)	..	..	..	..	..
	..	315(3)	..	..	0·29	..	0·47	..	0·26	..	0·57(2)	..	0·22	..	0·16(3)
6	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..
	..	290(2)	330(4)	..	..	..	..	..	..	..	..	..	..	..	0·23(2)
7	..	..	..	..	..	..	..	..	..	..	..	0·31	..	0·23(1)	..
	..	280(6)	..	..	0·32	..	0·49	..	0·21	..	0·54(1)	..	0·24	..	0·18(6)
8	..	..	..	0·55	..	0·68	..	0·57	..	0·90(3)	..	..	..	..	..
	..	315(2)	..	..	0·33	..	0·54	..	0·31	..	0·64(2)	..	..	..	0·16(2)
9	..	..	..	0·40	..	0·57	..	0·5	..	0·78(2)	..	..	..	..	..
	..	250(3)	..	..	0·22	..	0·50	..	0·22	..	0·61(1)	..	..	..	0·16(3)

10	.. ..	.. ..	.. ..	.. ..	.. ..	.. ..	.. ..	.. ..	.. ..	.. ..	.. ..	.. ..	.. ..	.. ..	.. ..
11	.. ..	.. $350(_7)$	.. $380(_6)$	.. ..	.. 0·60	.. ..	.. 0·93	.. ..	.. 0·60	.. ..	.. $0·97(_2)$	.. ..	.. $0·34(_2)$	.. ..	.. $0·24(_7)$
12	.. ..	.. $385(_8)$	.. $390(_5)$	0·93 ..	.. ..	1·00 ..	.. ..	0·98 ..	.. ..	$1·12(_1)$ ..	.. ..	.. ..	.. ..	.. ..	.. $0·31(_6)$
13	500 ..	.. $340(_7)$	.. ..	0·8 ..	.. 0·7	1·10 ..	.. 1·0	0·80 ..	.. 0·7	$1·10(_8)$ ..	.. $1·0(_8)$	.. ..	.. ..	$0·31(_2)$ ..	.. $0·28(_7)$
14	.. ..	.. $345(_4)$	.. ..	.. ..	.. 0·63	.. ..	.. 0·63	.. ..	.. 0·59	.. ..	.. $0·80(_1)$	.. ..	.. ..	.. ..	.. $0·31(_4)$
15	.. ..	.. ..	.. ..	.. ..	.. ..	.. ..	.. ..	.. ..	.. ..	.. ..	.. ..	.. ..	.. ..	.. ..	.. ..
16	.. ..	.. $340(_4)$	.. ..	0·51 ..	.. 0·42	0·75 ..	.. 0·76	0·41 ..	.. 0·44	$0·86(_4)$ ..	.. $0·80(_3)$	.. ..	.. $0·29(_2)$	.. ..	.. $0·22(_4)$
17	$450(_1)$ ..	.. 280	.. ..	.. ..	.. ..	.. ..	.. ..	.. ..	.. ..	.. ..	.. ..	.. ..	.. ..	$0·21(_2)$ ..	.. $0·15(_2)$
18	460 ..	.. $360(_4)$	.. ..	0·4 ..	.. 0·71	0·83 ..	.. 0·81	0·50 ..	.. 0·56	$0·99(_2)$ ..	.. $0·88(_1)$	.. ..	.. ..	$0·44(_1)$ ..	.. $0·25(_4)$
19	No specimens received.														
20	.. ..	.. $250(_8)$	.. ..	0·44 ..	.. 0·23	0·55 ..	.. 0·45	0·37 ..	.. 0·23	$0·72(_3)$ ..	.. $0·53(_3)$	.. ..	.. 0·22	.. ..	.. $0·15(_8)$
21	$340(_3)$ ..	.. $260(_7)$	.. ..	0·5 ..	.. 0·37	0·65 ..	.. 0·62	0·48 ..	.. 0·33	$0·83(_5)$ ..	.. $0·69(_9)$	0·26 ..	.. 0·22	$0·19(_3)$ ..	.. $0·16(_7)$
22	.. ..	.. $355(_9)$	.. ..	0·76 ..	.. 0·45	0·86 ..	.. 0·58	0·67 ..	.. 0·40	$0·96(_4)$ ..	.. $0·71(_9)$	.. ..	.. 0·39	.. ..	.. $0·31(_9)$

SUMMARY OF MEAN VALUES OF PHYSICAL PROPERTIES OF MARAETAI STONE—*continued*

NOTES.—(1) Figures in parentheses ( ) indicate the number of tests carried out: (2) figures set out as $^3/_7$: see text under "Shearing Test."

Site No.	Modulus of Rupture (lb./sq. in.). Intermittent Load on 10 in. Span.			Young's Modulus of Elasticity in Compression (lb./sq. in. × 10⁻⁶). Initial Run.				Second and Third Runs.				Modulus of Elasticity in Flexure (lb./sq. in. × 10⁻⁶).			
			Continuous Loading on 4 in.	At Zero Strain.		Mean to Half Maximum.		At Zero Strain.		Mean to Half Maximum.		At Zero Strain.		Mean to Half Maximum.	
	Dry.	Wet.		Dry.	Wet.	Dry.	Wet.	Dry.	Wet.	Dry.	Wet.	Dry.	Wet.	Dry.	Wet.
	15.	16.	17.	18.	19.	20.	21.	22.	23.	24.	25.	26.	27.	28.	29.
23	.. ..	.. 230(5)	.. ..	0·42 ..	.. 0·26	0·59 ..	.. 0·52	0·44 ..	.. 0·27	0·74(2) ..	.. 0·63	.. ..	.. 0·28	.. ..	.. 0·16(5)
24	450(2) ..	.. ..	.. ..	.. ..	.. ..	.. ..	.. ..	.. ..	.. ..	.. ..	.. ..	0·36(2) ..	.. 0·31	0·21(2) ..	.. 0·23(3)
25	.. ..	.. 300(3)	.. ..	.. 0·41	.. ..	.. 0·61	.. ..	.. 0·35	.. ..	.. 0·79	.. ..	.. ..	.. ..	.. ..	.. ..
26	No specimens received.														
27	.. ..	.. ..	.. ..	.. ..	.. 0·32	.. ..	.. 0·59	.. ..	.. 0·30	.. ..	.. 0·72	.. ..	.. ..	.. ..	.. ..
28	380(1) ..	.. 215(1)	.. ..	.. ..	.. ..	.. ..	.. ..	.. ..	.. ..	.. ..	.. ..	0·23 ..	.. ..	0·18(1) ..	.. 0·17(1)
29	310(1) ..	.. ..	.. ..	0·48 ..	.. ..	0·63 ..	.. ..	0·37 ..	.. ..	0·74(1) ..	.. ..	0·41 ..	.. ..	0·28(1) ..	.. ..
30	345 ..	.. 235(3)	.. ..	0·31 ..	.. 0·23	0·65 ..	.. 0·51	0·37 ..	.. 0·23	0·80(2) ..	.. 0·61(2)	0·32 ..	.. 0·23	0·24(1) ..	.. 0·15(3)
31	No specimens received.														
32	.. ..	.. 215(1)	.. ..	.. ..	.. 0·25	.. ..	.. 0·47	.. ..	.. 0·22	.. ..	.. 0·60(1)	.. ..	.. 0·15	.. ..	.. 0·12(1)

33	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..
	..	290($_{2}$)	..	..	0·26	..	0·46	..	0·29	..	0·56($_{1}$)	..	0·18	..	0·14($_{2}$)
34	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..
	..	215($_{2}$)	..	..	..	..	..	..	..	..	..	..	0·20	..	0·16($_{2}$)
35	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..
	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..
36	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..
	..	215($_{4}$)	..	..	0·36	..	0·53	..	0·32	..	0·61($_{2}$)	..	0·23	..	0·17($_{4}$)
37	No specimens received.														
38	..	..	..	0·43	..	0·56	..	0·36	..	0·74($_{2}$)	..	..	..	..	..
	..	190($_{1}$)	..	..	0·29	..	0·44	..	0·26	..	0·51($_{1}$)	..	..	..	0·08($_{1}$)
39	260($_{1}$)	..	..	0·22	..	0·35	..	0·22	..	0·45($_{4}$)	..	..	..	0·15($_{1}$)	..
	..	125($_{4}$)	..	..	0·24	..	0·33	..	0·19	..	0·35($_{2}$)	..	0·13	..	0·07($_{3}$)
40	..	..	..	0·34	..	0·52	..	0·36	..	0·59($_{1}$)	..	..	..	..	..
	..	..	..	..	0·21	..	0·39	..	0·21	..	0·45($_{1}$)	..	..	..	..
41	250($_{4}$)	..	..	0·23	..	0·40	..	0·22	..	0·54($_{2}$)	..	0·61	..	0·35($_{3}$)	..
	..	180($_{3}$)	..	..	0·20	..	0·32	..	0·22	..	0·38($_{2}$)	..	0·42	..	0·23($_{3}$)
42	..	..	..	..	.	..	..	..	..	..	..	..	..	..	..
	..	125($_{4}$)	..	..	..	..	..	..	..	..	..	..	..	..	0·08($_{3}$)
43	340($_{1}$)	..	..	0·61	..	0·69	..	0·48	..	0·84($_{1}$)	..	0·73	..	0·26($_{1}$)	..
	..	275($_{3}$)	..	.	0·38	..	0·53	..	0·38	..	0·59($_{2}$)	..	0·5	..	0·26($_{3}$)
44	215($_{1}$)	..	..	0·45	..	0·57	..	0·43	..	0·75($_{4}$)	..	0·46	..	0·42($_{1}$)	..
	..	270($_{4}$)	..	..	0·29	..	0·51	..	0·28	..	0·58($_{4}$)	..	0·27	..	0·17($_{4}$)
45	..	..	..	0·51	..	0·64	..	0·44	..	0·85($_{1}$)	..	..	..	..	..
	..	300($_{4}$)	..	..	0·33	..	0·47	..	0·31	..	0·56($_{2}$)	..	0·24	..	0·20($_{4}$)

SUMMARY OF MEAN VALUES OF PHYSICAL PROPERTIES OF MARAETAI STONE—*continued*

NOTES.—(1) Figures in parentheses ( ) indicate the number of tests carried out; (2) figures set out as $^3/_7$: see text under "Shearing Test."

Site No.	Modulus of Rupture (lb./sq. in.).			Young's Modulus of Elasticity in Compression (lb./sq. in. × 10^{-6}).								Modulus of Elasticity in Flexure (lb./sq. in. × 10^{-6}).			
	Intermittent Load on 10 in. Span.		Continuous Loading on 4 in.	Initial Run.				Second and Third Runs.				At Zero Strain.		Mean to Half Maximum.	
				At Zero Strain.		Mean to Half Maximum.		At Zero Strain.		Mean to Half Maximum.					
	Dry.	Wet.		Dry.	Wet.	Dry.	Wet.	Dry.	Wet.	Dry.	Wet.	Dry.	Wet.	Dry.	Wet.
	15.	16.	17.	18.	19.	20.	21.	22.	23.	24.	25.	26.	27.	28.	29.
46	..	270(1)	..	..	0·43	..	0·69	..	0·39	..	0·74(1)	..	0·21	..	0·17(1)
47	..	345(7)	..	..	0·67	..	0·67	..	0·50	..	0·76(2)	..	0·48	..	0·31(1)
48	..	340(2)	..	..	..	..	..	..	..	..	..	..	..	..	0·22(2)
49	..	300(5)	..	0·49	0·43	0·57	0·71	0·39	0·42	0·70(1)	0·75(2)	..	..	..	0·22(5)
50	..	350(2)	..	..	..	..	0·65	..	0·40	..	0·74(1)	..	..	..	0·25(2)
A1	..	325(4)	..	..	..	..	..	..	..	..	..	..	0·38	..	0·28(4)
A2	..	325(2)	..	..	..	..	..	..	..	..	..	..	..	..	0·27(2)
B1	..	310(3)	..	..	..	..	..	..	..	..	..	..	..	..	0·20(3)

ACKNOWLEDGMENTS

Acknowledgments are due to the Chief Electrical Engineer, Public Works Department, for permission to publish this report; to Messrs. Bloodworth and Fisher, of the Hydro-electric Branch, for ready co-operation and suggestions; to the staff of the Fletcher Construction Co.'s stone-yard for their co-operation and courtesy during the cutting and marking of the test specimens; to the Director of the Dominion Physical Laboratory for his encouragement in the work; and, finally, to the various members of the staff concerned in the construction of equipment or the carrying-out of the tests, some of whom did much of the tedious routine work and calculations with great care. Well over 2,450 tests were carried out, varying in testing time from five minutes to two or three days.

LITERATURE

Information of geological and engineering interest for the reader is contained in a "Geological Report on the Maraetai Section of the Waikato River," by J. Healy, New Zealand Geological Survey Division, and in "Maraetai Power Scheme: Report on Investigations," which is a summary of several geological reports as they apply to the engineering aspects, by M. Fisher, Hydro-electric Branch, Public Works Department, Wellington.

A description of the physical appearance and composition of ignimbrites is contained in an article by Dr. P. Marshall in the *Proceedings of the Royal Society of New Zealand*, Vol. 64, 1935, entitled "Acid Rocks, Taupo-Rotorua Volcanic District."

Reference has also been made to "Johnson's Materials of Construction," rewritten by James Ashton and M. O. Withey, 8th edition, pp. 249-258.

NEW ZEALAND IRONSANDS

The Editor,

New Zealand Journal of Science and Technology,

Wellington.

DEAR SIR—

In my recent paper on the New Zealand ironsands (this *Journal*, Vol. 26 (Sec. B), 227-38) my address was given as Canterbury University College, Christchurch. While that is my present address, I wish to point out that the original, from which the published paper is an adaptation, was a report written for the Secretary of the Department of Scientific and Industrial Research while I was on the staff of the Dominion Laboratory. I thus had the facilities of the Dominion Laboratory at my disposal, and of the Department as a whole. I regret that these facts were inadvertently omitted from the paper as published, and would be glad if you would publish this note in order to remove any misunderstanding caused thereby.

I remain, Sir

Yours faithfully,

B. H. MASON.

STRESS ANALYSIS BY PHOTOELASTIC METHOD

TWO-DIMENSIONAL PRINCIPLES AND PRACTICE

By W. B. DUNN, D. E. CAMPBELL, and G. S. MARSHALL, Dominion Physical Laboratory, Department of Scientific and Industrial Research

[*Received for publication, 25th July, 1945*]

Summary

The use of the photoelastic method for analysing indeterminate stress problems is presented and the possibilities and limitations of the method discussed. The general principles and construction of the laboratory equipment is outlined. The preparation of the model is described, with emphasis on the care required in all aspects of the operation. The description of the photographic technique presents the necessity of clear photographs to give accurate patterns. The pattern is analysed by the method described in the final section. An illustrative example shows that calculations are routine and that by the use of mathematical aids accurate results are quickly obtained.

NOTATION

OX and OY	.. Co-ordinate directions.
P and Q	.. Principal stresses.
C_1 and C_2	.. Photoelastic coefficients.
N ..	.. Refractive index.
R ..	.. Light phase retardation.
L ..	.. Model thickness.
M ..	.. Numerical intiger.
W ..	.. Applied load.
λ ..	.. Wave-length of light (monochromatic).
N ..	.. Number of wave-lengths (or fringe order).
K ..	.. Constant.
F ..	.. Fringe value of model.
f ..	.. Material fringe value for 1 in. thickness.
A ..	.. Area of cross section.
θ ..	.. Isoclinic angle.
τ ..	.. Shear stress value if with lower case letters—*e.g.*, τxy denotes directions in which shear is acting.
σ ..	.. Stress value—lower case letters denote direction of stress.
δ ..	.. In front of any value denotes any small change in value.
ΔT ..	.. Difference of two shear values.

PART I.—GENERAL

INTRODUCTION

THE thesis outlining the use of photoelasticity in two-dimensional stress analysis presented by Coker and Filon in 1911 offered to the design engineer a long-needed method of stress analysis. The paper was compiled from experimental data taken at London University. The modern trend of engineering design has been toward lighter and more economical structures requiring low factors of safety. This practice would be dangerous if there where not available reasonably accurate methods of stress analysis. Photoelasticity makes it possible to " see " the stresses in a model of the prototype structure. This has distinct advantages over complicated mathematical methods in which surface stresses alone are measured. The photoelastic method of stress analysis is a useful and economical method of accurately measuring internal stresses where rigorous analysis of indeterminate structures is required. Surface stresses can be easily found and the problem of stress concentrations can be brought into the field of simple analysis. The photoelastic method is not adaptable to all stress measurements but can be used in a wide variety of cases.

Since the work of Coker and Filon rapid advances have been made in both technique and materials. England, America, Germany, and Japan have each contributed valuable work, and it is of interest, although beyond the scope of this paper, that during the last decade the method has been extended to cover three dimensional models.

PRINCIPLES

(*a*) *General.*—In the year 1816 Sir David Brewster discovered that if a transparent isotropic material is subjected to stress it exhibits the phenomenon of double refraction. This property has since been investigated by Fresnel, Neumann, Pockels, and others, and from their observations the following laws have been derived :—

(1) The directions of polarization corresponding to a given wave normal are along the directions of principal stress in the wave front :

(2) If P and Q are the two principal stresses and Np and Nq the refractive indices of the material in the directions P and Q respectively and No the refractive index of the unstrained material—

$$\begin{aligned} Np - No &= C_1Q + C_2P \\ Nq - No &= C_1P + C_2Q \end{aligned}$$

(3) The above statements hold over a considerable range of stress, in general not exceeding the elastic limit. The coefficients C_1 and C_2 are the photoelastic coefficients, C_1 is the *transverse* and C_2 the *direct*.

If the light passes through a plate of thickness L such that the directions and magnitudes of the principal stresses are the same throughout and there are no stresses along the light path the relative retardation,

$$\begin{aligned} R &= L\,(Np - Nq) \\ &= C_1 - C_2\,(Q - P)\,L \\ &= K\,L\,(P - Q) \end{aligned}$$

(*b*) *Circularly Polarized Light.*—The property of double refraction as exhibited by mica, tourmaline and calcite crystals can be briefly described as the ability to split an entrant plane polarized beam of light into two vectors of plane polarized light at some angle to each other. The two vectors traversing the material suffer a relative phase retardation. The so-called commercial quarter-wave plate is a sheet of mica with its faces parallel to the optic axis. The light, which is plane polarized, enters normal to the plane of the plate and with the plane of polarization at 45° to the optic axis. This ensures that the two vectors are equal in amplitude. (The optic axis is one principal plane of vibration and the other one is at 90° to the optic axis.) If the thickness of the mica is such that one emergent vector becomes 90° out of phase with the other emergent vector, then the resultant vibration is a circular motion. The emergent light is said to be circularly polarized.

If two quarter-wave plates were placed one behind the other with optic axes in the same plane, to form a half-wave plate, the relative phase retardation of the light vectors would be 180°. Consider now the case of plane polarized light falling on such a half-wave plate with its plane of polarization at 45° to the optic axis. Referring to the vector diagram (Fig. 1), the entrant plane polarized vector is OB split up into vectors OX = +1 and OY = +1. With the emerging vectors having a resultant

phase retardation of 180° (that is, when OX $= +1$, OY $= -1$ or OX $= -1$, OY $= +1$), the resultant emerging vibration is plane polarized as vectors OA or OA_1 respectively (*i.e.*, the emerging light is polarized in a plane 90° to the light incident on the half-wave plate).

Similarly, the placing of two quarter-wave plates one behind the other with optic axes at right angles to each other brings the plane of polarization back to the original plane.

(*c*) *Use of Photoelastic Phenomenon.*—The value R in R $=$ KL (P $-$ Q) may have any value, but at the particular values R $= 2m\pi$ and R $= (2m + 1)\pi$ the temporary double refraction corresponds to a full-wave and a half-wave plate respectively. This means any incident plane polarized light vector will emerge in the same plane as entry if R $= 2m\pi$, or rotated through 90° if R $= (2m + 1)\pi$. Therefore, to analyse this effect the following are essential :—

(*a*) A system to give plane polarized light.
(*b*) A system to analyse the emerging light.

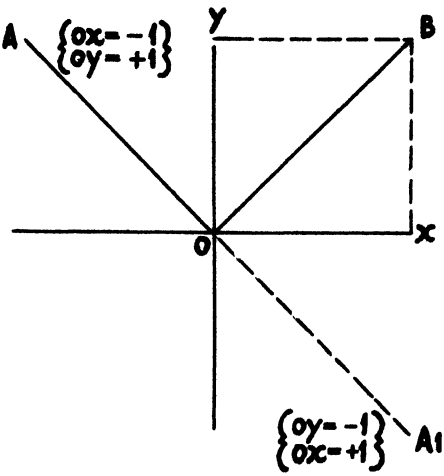

FIG. 1.—Theory of half-wave plate.

The simplest equipment would be two sheets of Polaroid, one in front of a stressed model and one behind. Light passing through the first polaroid would enter the model plane polarized. The emerging light vector at points where R $= 2m\pi$ would vibrate in the same plane of polarization as before, but at points where R $= (2m + 1)\pi$ the light vector would vibrate in a plane at 90° to the above.

The light would now pass into the second polaroid. If the plane of polarization of this sheet was at right angles to the original plane, only the vectors corresponding to R $= (2m + 1)\pi$ would be able to pass through.

This means that all over the sheet as viewed along the direction of the light there will be points of maximum darkness and maximum brightness. In effect these appear as bands of black and white lines (see Fig. 1A), which fade into each other. These lines from the original definition of "R" are loci of points where the value P–Q is constant.

In the use of plane polarized light the pattern above has superimposed upon it a second pattern. This is due to the fact that at certain places over the stressed sheet (or model) one of the planes of principal stress direction coincides with the plane of polarization and allows the light to pass straight

FIG. 1A.—Isochromatic pattern of model.

through. (The vector at 90° is zero.) The pattern from plane polarized light contains, therefore, two features—(*a*) a pattern of loci of points of constant principal stress difference (isochromatic pattern) and (*b*) a pattern of loci of points where a principal stress is parallel to the incident light vector (Isoclinic pattern). This information is sufficient to solve for all stresses (see Part III).

The isoclinic pattern may be eliminated by the use of circularly polarized light. This requires the placing of a quarter-wave plate on either side of the model and immediately adjacent to it, with the polaroid sheets remaining as before. By placing the optic axes at right angles to each other and at 45° to the original incident plane of polarized light, the light passing through the final polaroid is exactly as in the above case, except that the isoclinic pattern is eliminated. Circularly polarized light may be considered as two vectors vibrating in planes at right angles (see above). The circularly polarized light passing into the model at any point may then be considered as two vectors vibrating in the planes of the principal stresses and therefore independent of the isoclinic angle—*i.e.*, the angle between principal stress and plane of polarization.

With a combination of the above methods it is possible to separate both patterns.

Experimental proof of the theory can be found by three methods :—

(*a*) Cutting a small strip and loading in simple tension or compression so that the principal stress at right angles to the applied load is zero. By counting the fringes as they appear and plotting against the load, the relation between the two is shown to be linear.

(*b*) Loading a circular model equally at 4 points at 90° to each other and plotting the number of fringes appearing at the centre, against the value (P − Q) at the centre. In this case P and Q are calculable and (P − Q) can be shown to equal $\frac{8P}{\pi L d}$ where P is the load applied across one diameter, L = thickness of plate, d = diameter of plate.

(*c*) By loading two such disks which are exactly similar except for thickness, the number of fringes may be shown to be constant. The value K in the equation R = K (P–Q) is the only variable.

PART II.—TECHNIQUE

1. CONSTRUCTION OF EQUIPMENT

(*a*) *Polariscope.*—The apparatus required for interpreting photoelastic phenomenon is as follows : (1) a bench to mount the equipment, (2) a point source of light ; (3) an optical system to give both plane and circularly polarized light (polarizer) ; (4) fittings to make it possible to change the system of polarization simply and effectively ; (5) an optical system to give parallel light through the model ; (6) an analyser to collect the light, (7) a screen on to which the image may be projected, (8) a camera to keep permanent records, (9) subsidiary apparatus to ensure correct alignment of parts 1 to 8.

The assembled equipment is the polariscope. The diagram (Fig. 2) shows the polariscope made and installed at the Dominion Physical Laboratory (New Zealand) to analyse two dimensional models.

The optical bench (1) is made up of four 1-in.-diameter mild-steel rods fitted into four equally spaced brackets. These brackets are identical in shape and size and rest on two wooden tables. Each bracket has two

levelling screws in order to ensure that the top of the bench is horizontal throughout its entire length. Running along the top are the stands (2) carrying the main equipment. Along one edge of these stands are two feet cut to a V shape to slide along the 1 in. rod. A small hook clamp is attached for locking purposes. The centre stem is set in the base so as to allow for slight lateral and longitudinal movement once the base is clamped to the bench. The hollow stem is provided with a set screw to allow for vertical positioning of the particular fitting.

The light source (3) is a 75-watt, tungsten-filament lamp, run from a 230/12v. transformer. It is carried on a stem to allow for both angular and vertical movement. It is essential that the filament be at right angles to the light path. The cover permits only a small beam to pass out and cuts off all unnecessary light.

The two condensers (4) focus the light on to the polarizer (5). The polarizer consists of a sheet of polaroid followed by a mica quarter-wave

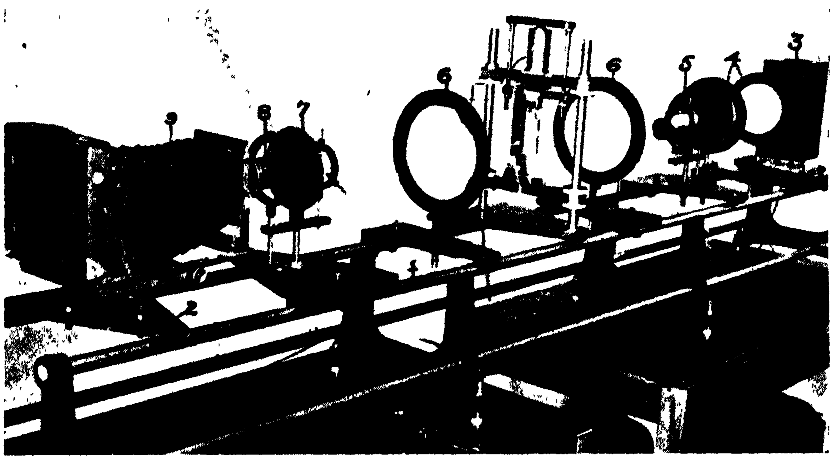

FIG. 2.—Polariscope.

plate. The stand holding the two parts of the polaroid is a 6-in.-diameter circle. Around the outer circumference at 5° intervals is drilled a series of holes. The polaroid is fixed to a centre bushing and is free to rotate. A small arm fitted to the bushing enables the polaroid to be moved to any angle. The arm has a small spring-loaded foot which fits into the drilled holes and ensures the correct setting for each 5°. The quarter-wave plate is fitted in a similar bushing to a square plate pivoted at one corner to enable it to be swung in or out of the light path as required. The arm is, in this case, an indicator pointing to the drilled holes. A removable filter is mounted next to the quarter wave plate.

From the polarizer the light passes through two large 8 in. condensers (6) so arranged as to give parallel light. The light then passes through an analyser (7), which is a replica of the polarizer but placed to allow the light to enter the quarter-wave plate first. At the end of the bench is a camera (9), into which the light is brought to focus through the compound lens system (8). The back of the camera has a ground glass plate fitted to permit visual inspection of the model.

To set up the equipment it is necessary first to level the bench and set the lamp to a suitable height. A telescope is then placed at the other end of the bench and set on infinity. As each component is put on it is positioned by sighting the filament of the lamp through the telescope. To get the

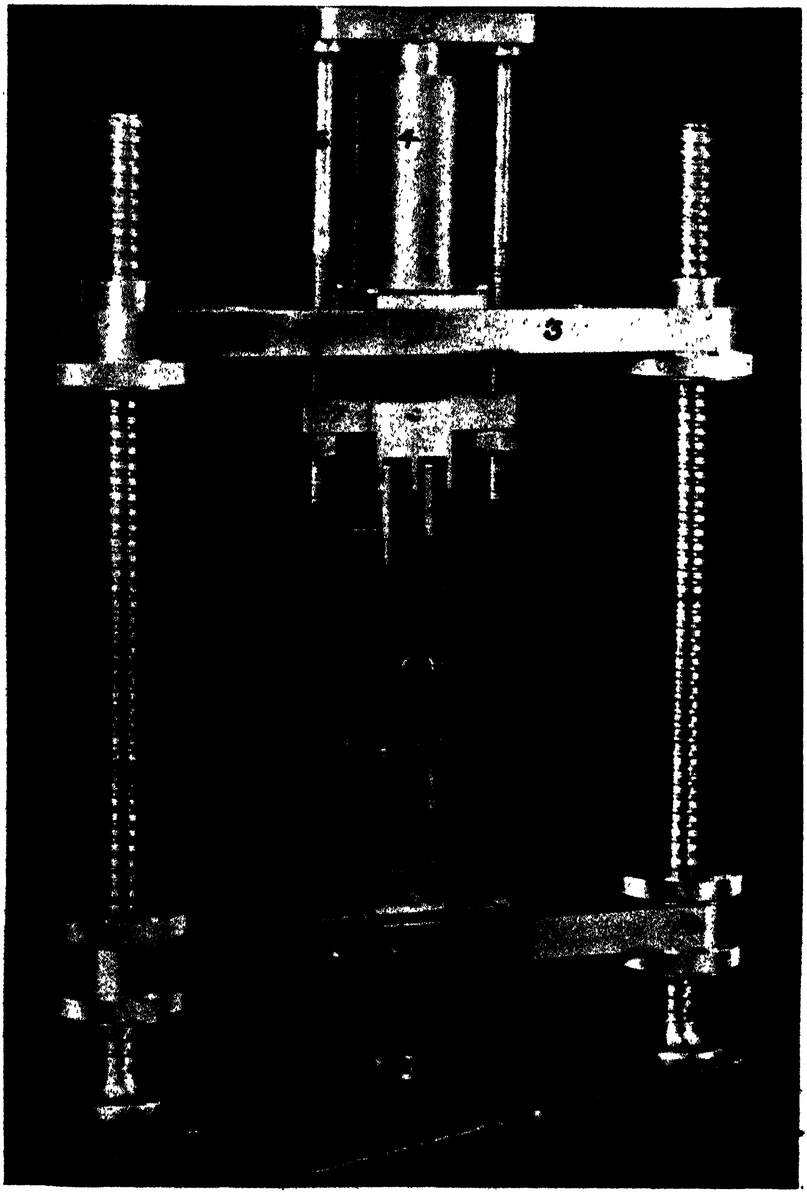

FIG. 3.—Loading machine (using tension model).

correct heights a target disk set on a stand is used. This is first fixed so that its centre point is exactly the same height as the filament; then each component is set so as to focus the light concentric with one of the target

rings. In this way all the parts are placed in their correct position. To set the polaroid a disk of photoelastic material loaded in one direction is used. The isoclinic for zero degree is along the diameter loaded. The disk is suspended by string along the line of the load. The polaroids,

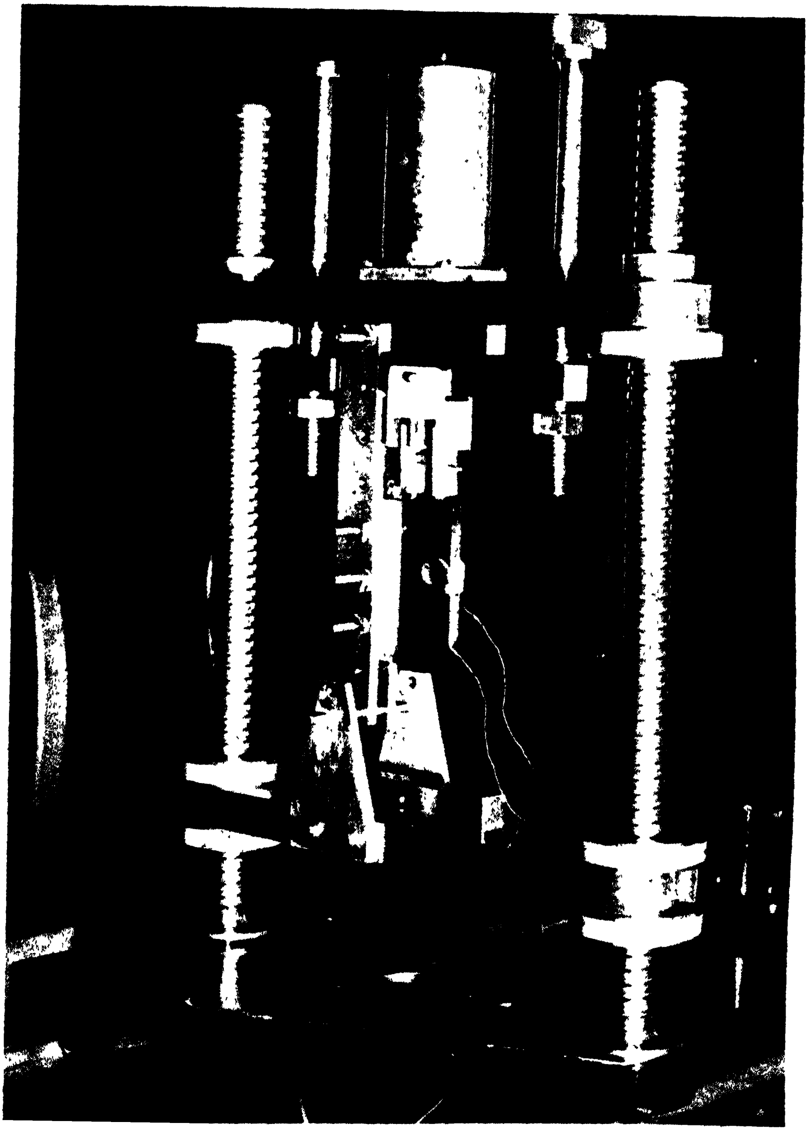

FIG. 4.—Loading machine (showing shear clamps).

previously crossed, can be swung until the model is clear and the isoclinics are distinct black lines. The polaroids must be set and the graduations (holes) on the polarizer marked for the correct zero. The disk is removed and the quarter-waves plates are set by rotating until maximum brightness occurs. These are then fixed and set.

(*b*) *Loading Equipment.*—The equipment used for loading photoelastic models must be versatile in that it can readily be adapted for all types of loading. The three most common loads are—

(*a*) Tension.
(*b*) Compression.
(*c*) Shear.

Torsion is beyond the scope of two dimensional work.

The loading equipment used at the Dominion Physical Laboratory is readily adaptable to the three types. A main stand ((1), Fig. 3) sits on the polariscope bench, and supports two threaded side rods (2). The top adjustable cross-arm (3) carries a piston and oil cylinder (4) supplied from a hand pump and gauge. The top of the piston carries a simple beam (5) with rods (6) on either side attached to a lower beam (7). Clamps fitted to this and the lower adjustable cross-arm (8) provide holds for tension pieces. By extending the distance to the lower beam (7) a model fitted between the top adjustable arm (3) and the beam (7) is compressed. By fitting clamps between the two adjustable arms (3 and 8) and clamping the model to these the tension or compression method is converted to a shear method. The clamps used in all three methods (except the main shear clamps) are free to pivot so as to automatically adjust for alignment.

The loading apparatus with shear clamps is shown in Fig. 4.

2. PHOTOELASTIC MATERIALS

The following properties are desirable in photoelastic materials:—

(*a*) *Clarity:* A material must obviously be transparent.

(*b*) *Hardness and Rigidity:* The material should be hard enough to sustain clamping during loading and machining without undue distortion.

(*c*) *Machinability:* Materials are unsuitable unless they can be easily machined by ordinary power machines.

(*d*) *Freedom from Initial Stresses:* Materials containing any stresses other than those set up during the experiment give inaccurate results. Most materials can be relieved of stress by annealing.

(*e*) *Linear Stress-Strain and Stress-Fringe Relation:* For any loading the plotting of stress against strain, and stress against number of fringes appearing, must be linear.

(*f*) *Absence of Creep:* After a certain time has elapsed the appearance of the stresses must not be altered due to changes in the fringe value (K in $R = KL(P-Q)$) or changes in the strain for any given load. This must also hold for moderate temperature changes.

(*g*) *Optical Sensitivity:* This is the most important of all properties and refers to the value of K above. This value must be kept small. A loaded model is usually covered with many fringes of varying order corresponding to the value (P–Q). If the value K is large, the model will have only a few fringes and the necessity for interpolation will cause results to be inaccurate.

The introduction of plastics has considerably widened the materials available to the stress analyst. Glass is a photoelastic material, but cannot be suitably machined and has a very high fringe value. Of the plastics, nitro-cellulose (celluloid) was the first used with considerable success. It is still used because of its cheapness and ease of machining. However, its large fringe value (Table 1) has caused its displacement by clear bakelite, which answers to most of the above requirements. Bakelite shows changes

in properties after five to six hours, but, with this limitation, is an ideal material. Other suitable plastics of the phenol formaldehyde group are Catalin and Marblette. An allyl resin known as Columbia Resin (C.R. 39) has been found to be suitable.

TABLE I.—PROPERTIES OF PHOTOELASTIC MATERIALS
(Room temperature approximate values)

Material.	Fringe Value in lb./sq. in. shear/in. Thick.	Ultimate Strength Tensile lb./sq. in.	Elastic Limit lb./sq in.	Young's Modulus. lb./sq. in.
(1) Celluloid ..	110–190	$(4 \cdot 9–8 \cdot 5) \times 10^3$	$(3 \cdot 9–7 \cdot 5) \times 10^3$	$(2 \cdot 0–3 \cdot 9) \times 10^5$
(2) Marblette ..	38	..	..	$5 \cdot 3 \times 10^5$
(3) Phenolite (Japan)	32·6	10,700	4,300	$5 \cdot 25 \times 10^5$
(4) Trolon (Germany)	31·5	..	1,420	$3 \cdot 55 \times 10^5$
(5) Glass.. ..	490–1500	..	..	9×10^6
(6) Bakelite (61–893)	43·0	17,000	7,000	$6 \cdot 15 \times 10^5$
(7) Columbia Resin (C.R. 39)	86·6	5,000–6,000	..	$2 \cdot 5–3 \cdot 3 \times 10^5$

(1) M. Frocht. (2) Solakian. (3) Z. Tuzi (4) G. Oppel. (5) M. Frocht.
(6) M. Frocht (7) *Plastics Bulletin No. 2*, Oct. 15, 1943.

3. PREPARATION OF MODELS

The Dominion Physical Laboratory has used bakelite for all models, but the procedure for other plastics is almost identical with slight variations in the machining in the case of C.R. 39.

The material is supplied in sheet form and before use must be thoroughly annealed. The annealing process is carried out in a temperature controlled oil bath and is as follows :—

(1) Preheat bath to 240° F. (115° C.).

(2) Place sample on a sheet of plate glass in bath and keep at temperature for one hour.

(3) Cool in bath at rate of 15° F./hr. (approximately 11 hr. 40 min.).

The sheet can then be stored and used as required.

The model to be made is scaled from the prototype to a size suitable for the polariscope and a blank cut from the plastic sheet so as to leave $\frac{1}{16}$ in. clearance from the finished lines. A jig saw is suitable for this operation.

The blank is now ready for polishing. Sheet bakelite is opaque as received from the manufacturers, but by polishing becomes transparent with a light amber tinge. The first process consists of grinding the faces with emery paper. This is done by successive stages, finishing up with a fine grade such as 400. Emery papers suitable are 100, 200, 320, and 400. The grinding is done first in one direction, and then on change of emery grade, at right angles to the first direction. This ensures that all marks of the previous grading are eliminated before next change of grading.

The rough polish is done with a 600 grit on a cloth lap. The model is finally polished with jeweller's rouge.

The model is now scribed with the final sizes and machined to shape. The edges are machined with end mills. The machining should be done with slow feeds and high cutter speeds. Cuts of 0·005 in. can be used up to the last 0·005 in. The last cuts should be one of 0·002 in., two of 0·001 in.,

and two of 0·0005 in. The last feeds should be especially slow. Edges requiring turning can be machined in a lathe using a similar procedure. Irregular surfaces can be finished with either a hand or rotary file. A pantograph engraving machine can also be used for irregular surfaces. The greatest care must be taken to keep the surface free from scratches during machining and the model may be masked with paper. All tools should be sharp and used for photoelastic work only. Drills used for boring holes should have the point ground at an included angle of approximately 75° to 85°. Larger holes should be drilled with a small drill followed by end mills increasing by $\frac{1}{32}$ in. diameter. Coolants such as kerosene, light oil, baking-soda, and water or air may be used but are not absolutely necessary. In all machining operations the model should be securely set up and clamped so that edges are normal to the faces. The machining of the model is most important, and unless the recommended procedure is followed the model will show machining stresses large enough to invalidate the results.

4. EXPERIMENTAL TECHNIQUE

The experimental work on the photoelastic model must be done within a few hours of completion of machining, due to the time-edge effect. This phenomenon takes place when machined Bakelite is left exposed to room humidity for any length of time. Depending on the relative moisture content of model and atmosphere, the model takes up or gives off moisture along the surfaces exposed. The resulting contraction or expansion of the edge causes compression or tension in the model.

The model is first placed in the loading machine on the polariscope bench. The importance of accurate alignment and accurate load application is paramount.

The model must have its parallel faces normal to the light path, and its edges must lie along the light path. This ensures that the stresses will be normal to the ray of light and that the edge will be clearly defined as a sharp line. If the former does not hold, the fringes will not be true measurements of principal stress difference. If the latter does not hold, the boundaries will be vague and the exact position of any fringe as it runs into the boundary hard to define. Boundary stresses are often important in stress analysis.

In the event of the method of load application being incorrect a true representation of prototype conditions is impossible. To give correct load distribution it is necessary to load through some form of equalizer to produce uniform distribution. A piece of cardboard is the simplest means of obtaining uniformity. The cardboard is placed between model and load. With a high ratio of $\frac{\text{prototype}}{\text{model}}$ great accuracy in applying the proper loads in the proper place is required.

When the model is correctly aligned the load is applied until the fringe order at the highest point indicates a stress slightly below yield point. As the first fringe appears the position is noted, and when it is considered that the number of fringes appearing at this point has reached the safety limit the loading is stopped. For Bakelite this is about eleven fringes. The load is left at this value for fifteen to thirty minutes to allow for a complete bedding in of all parts. Any changes under load due to strain and optical creep do not then occur during the photography of the fringes. During this period the camera is focused and the plates loaded ready for for use.

When the model is ready the polaroids and quarter-wave plates are both set at the zero position. The pattern is photographed.

The quarter-wave plate is now removed and a second photograph taken. The polaroid on both analyser and polarizer are next moved through angles of 10° so as to vary the plane of polarization. The completed set of photographs comprises an isochromatic pattern at full load and photos of isochromatic plus isoclinic pattern for each 10° angle between 0° and 90°. As the isochromatic pattern is always constant, isoclinics for each angle can be derived from the difference between each photo and the original pattern taken with circularly polarized light. A composite drawing of all this information, called the isoclinic pattern, is compiled.

The compiling of the isoclinic pattern is the most difficult operation in applied photoelasticity, and any inaccuracy in the operation will cause considerable errors in the results. Separating the two patterns needs careful inspection and drawing. The Dominion Physical Laboratory developed a technique which depended upon the fact that a loaded model will change its isochromatic pattern during the load application, but not the isoclinic pattern. This property is obvious from Part I.

The operation consists of taking each isoclinic photo with the load moving during exposure. The intensity of light from the source is reduced and during a thirty-second exposure the load is moved through three cycles—from one-third full load to two-thirds full load—at a uniform rate. The prints show the isoclinic only. The reason for not taking the cycle from zero to full load is that at zero load the isoclinic disappears and a continual restressing to full load may cause breaking due to fatigue. The isoclinics are drawn on tracing-paper by viewing each negative, illuminated from behind, in turn. The isoclinic values are then plotted at regular sections across the model, and smooth curves drawn for each section. The isoclinics are redrawn from these curves. The final isoclinics are inked and photographed.

The developing of photos should be done as soon after exposure as possible, so that a check on the work can be obtained. Any errors in procedure can be seen and the model used again before removal ; otherwise appreciable edge effect occurs. The light used should be monochromatic green produced by placing a filter next to the polarizer. The type of plate used and exposure depend on the operator and developing technique. The Dominion Physical Laboratory practice is to use Kodak Ortho X Plates exposed for ten seconds.

The only information remaining to be found is the fringe value and the fringe order. The latter is obtained by loading and unloading the model and counting each fringe as it appears from each source and when fully loaded noting the position of each fringe and recording on a rough sketch. On each fringe the number is written—*e.g.*, the first to appear from any point is No. 1, the fifth No. 5, &c. The first fringes appearing from different points are still No. 1, whether they appear at different loading times or not. This applies to all values.

The fringe with number 2 on it means that P–Q along the isochromatic is twice what P–Q is for number 1. From general principles if the load difference doubles a second fringe appears due to a retardation of two wave-lengths.

The fringe value is found by plotting the fringe order against load for a simple tension piece (cut from the same sheet) as described under "Principles," Section (*c*), Part I.

From $R = LK\,(P-Q)$. (Where L = thickness of plate.)

$$(P-Q) = \frac{R}{LK}$$

From the fact that the maximum shear at any point in a stressed body $= \frac{P-Q}{2}$

$$\text{Shear} = \frac{R}{2LK} = \frac{n\lambda}{2LK} = nF.$$

Where λ = wave-length of light (monochromatic).
n = number of wave-lengths retarded.
F is the fringe value and may be looked upon as the value of maximum shear stress at any point in a model corresponding to a fringe order of one.

$F = \frac{f}{L}$ where f is the fringe value of the material for 1 in. of thickness.

Therefore in a simple tension piece where shear maximum $= \frac{P}{2A}$ (Q is zero and P is load applied), $F = \frac{P}{2An}$ where n is fringe order for load P.

The material fringe value = FL

$$= \frac{PL}{2An} = \frac{P}{2dn}$$

where d = width of the model.

The information acquired is now as follows: (*a*) isochromatic pattern; (*b*) isoclinic pattern; (*c*) value of fringe orders on pattern; (*d*) fringe value of material.

PART III.—DERIVATION OF RESULTS

(1) CALCULATION OF THE PRINCIPAL STRESSES IN A TWO-DIMENSIONAL SYSTEM

The Shear Difference Method.—In any body subjected to a system of two dimensional forces (see Fig. 5), the shear stress along any co-ordinate system OX : OY at a point C is given by $(\tau xy)_c = \frac{P-Q}{2}\sin 2\theta$

where P = the greatest algebraic principal stress at C.
Q = the smallest algebraic principal stress at C.
θ = the angle between P and OX.

Photoelastic examination provides sufficient data to compute the shear at any point. From the material fringe value and the fringe order at point C the value $\frac{P-Q}{2}$ is given directly by definition

$$\frac{n_c f}{L} = \frac{P-Q}{2}$$

where n_c = fringe order at point C.
f = material fringe value
L = thickness of model.

The value $\frac{f}{L}$ is called the model fringe value. The isochromatic pattern furnishes the value n_c.

From the isoclinic pattern the angle θ is derived at point C, as by definition the isoclinic curves are loci of points where P makes a given angle with the reference axis (usually OX). This angle θ, in the isoclinic pattern, is usually drawn only for angles between 0 and 90° as it can be seen from the diagram if P moves to some angle between 90° and 180° the value $(\tau xy)_c$ is of the same value as the corresponding position in the first quadrant only the *direction* of $(\tau xy)_c$ has changed. (Note the value at $\theta = 110°$ is the same as at $\theta = 70°$). Between 180° and 360° the values and stresses are mirror images of those between 0° and 180°. A check on this fact is afforded by the definition for shear stress, as $\sin 2(110°) = -\sin 2(70°) = \sin 2(290°)$, showing only a change of sign (direction) in the second and fourth quadrants.

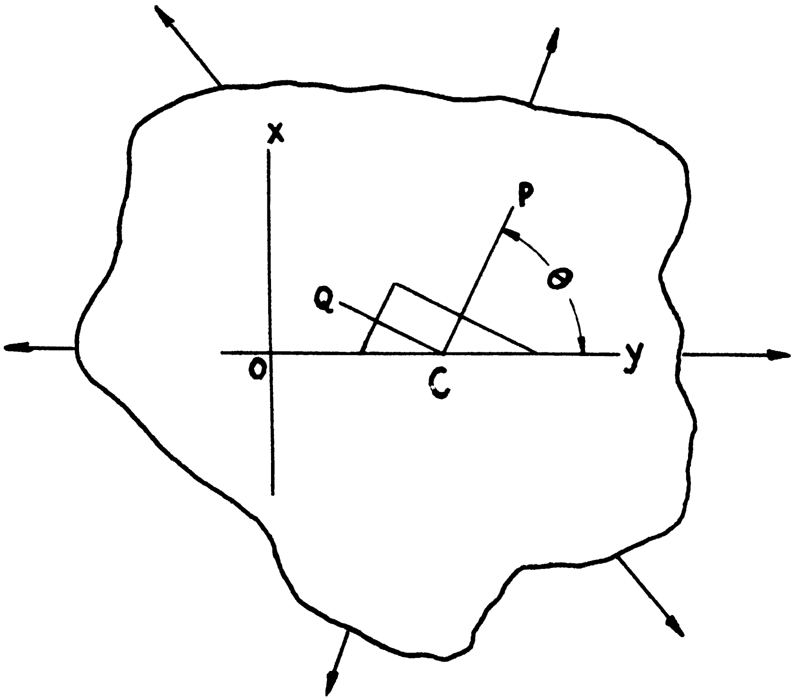

FIG. 5.—System under load.

The problem of the direction of the shear is solved by means of a simple rule. Taking a system of positive forces and the usual co-ordinate notation as shown in Fig. 6, the shear stresses are denoted by the following sign directions : $\rightleftarrows \downarrow \uparrow$ By combining the forces in the two positive directions the resultant is along the dotted line.

It can be seen that if the algebraically greater principal stress is in the first or third quadrants the system of positive shears is satisfied. If it is in the second and fourth the shear system is negative.

Another simple rule is to draw an approximate stress diagram at the point " C " in question. Draw in the normal and the major principal stress P. The direction of the shear stress on the normal side of OX is the same as the direction of the angle measured from the normal to P on the normal side.

The principle is shown in Fig. 7. Where the isoclinics are drawn only from 0° to 90°, a knowledge of the direction of P is required (0° to 90° may mean 180° to 90°). By practice and a knowledge of the loading system the determination of whether P is in the first or second quadrant becomes a matter of simple inspection.

In this respect the axes must be carefully watched. When the calculation is being taken from the OY direction the opposite of the above holds.

Three facts are now known :—

(a) $\frac{P-Q}{2}$ (or P—Q)

(b) θ

(c) The direction of the shear stress.

From these the whole system may be analysed. The shear difference method supplies σx and σy, the stresses along the OX and OY axes, directly. This is enough for most engineering problems. However, if P and Q (the

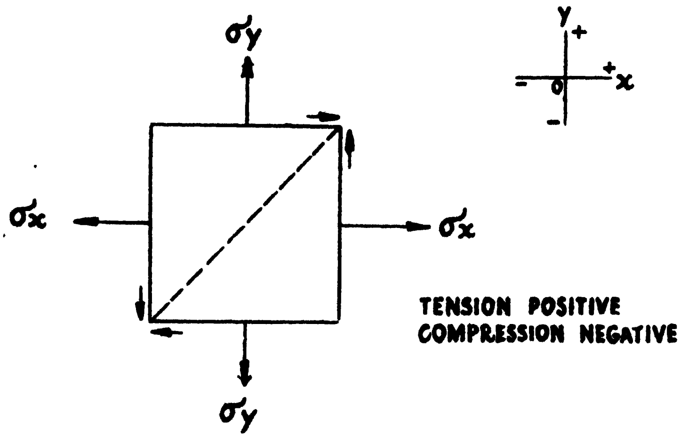

FIG. 6.—System of forces in equilibrium.

principal stresses) are required the two following simultaneous equations supply the information :—

$$\sigma y = P\sin\theta + Q\cos\theta$$
$$\sigma x - P\cos\theta - Q\sin\theta$$

From the expression for stress at any point along the axis of a co-ordinate system

$$(\sigma x)_c = (\sigma x)_0 \quad - \int_0^c \frac{\delta\tau xy}{\delta y}\ dx$$

as derived by Cartesian Co-ordinates from forces in equilibrium, it can be seen that the stress at any point C along a section OX in the OX direction can be found if the stress at some other point O on the same section and in the same direction is known. By breaking up the model for analysis into sections OX, OX_1 — OX_n the whole of the stresses at set points in the OX direction can be found as long as at one point in each section the stress is known. At free boundaries, at isotropic points where (P = Q) and at singular points where (P = Q = O)* the stress can easily be found from the

* Where P = Q = O, every direction is a principal stress direction. Many isoclinics will pass through such points.

isochromatic pattern. Thus all the information for the shear difference method of calculation is available.

Again, from the proven fact that—

$$\sigma y = \sigma x \pm \sqrt{(P-Q)^2 - 4\,\tau xy^2} \text{ (Mohr's stress circle)}$$

the stress in the OY direction can be found at each point and the whole stress system analysed.

Referring back to $(\sigma x)_c = (\sigma x)_o - \int_o^c \frac{\delta \tau xy}{\delta y}\, dx$ the problem of integrating the latter expression is to be overcome. The expression $\frac{\delta \tau xy}{\delta y}$ is the limiting value for change of shear in the OY direction at each point along the OX axis.

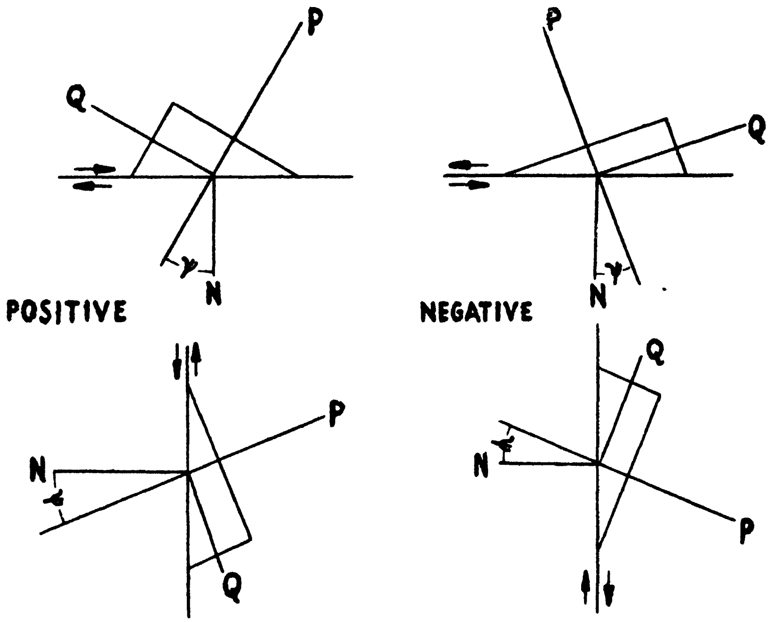

FIG. 7.—Derivation of shear directions.

For any section OX (Fig. 8) take two other sections OX′ and OX″ parallel to it and at the same distance from it. Along OX, OX′ OX″ plot P–Q, θ and the derived shear curves. Calling the distance between OX′ and OX″ $= dy$ the value of $\frac{\delta \tau xy}{\delta y}$ can be seen to be approximately equal to $\frac{\tau x_1 y_1 - \tau x_{11} y_{11}}{dy}$ at any point. By plotting the value of $\frac{\tau x_1 y_1 - \tau x_{11} y_{11}}{dy}$ along the OX axis it can be seen that the value of $\int_o^c \frac{\delta \tau xy}{\delta y}\, dx$ equals the area under curve between O and C.

The arithmetic may be greatly simplified by taking $dy = dx$. Then $\frac{\delta \tau xy}{\delta y} . dx = \tau x_1 y_1 - \tau x_{11} y_{11}$, and the integral value is equal to the area under the plotted values of this figure.

In computing, care must be taken with signs; "dx" is positive as it moves to the right, "dy" is positive as it moves upward, and $\delta\tau xy$ is positive when $\tau x_1 y_1$ is algebraically greater than $\tau x_{11} y_{11}$ (OX′ is above OX″). When "dx" = "dy" care must be taken to remember this and take it into account.

To finish the computing, take the point "O" where the stress σx is known and finish the calculating of σy across the section at points A, B, C - - N. For stresses in the OY direction the formula

$$\sigma y = \sigma x \pm \sqrt{(P-Q)^2 - 4\,\tau xy^2}$$

is used. P–Q is taken from the isochromatic value at the point and τxy from the computation $\tau xy = \frac{P-Q}{2} \sin 2\theta$. The $\pm$ signs are used depending on whether σy is greater or smaller algebraically than σx.

Illustrative Problem.—To show the use of the shear difference method a section of a model is calculated. The applied load was 250 lb. tension and the model held in shear on one side (Fig. 9).

The section under consideration is marked OY, and the two sections used for calculating are marked OY_1 and OY_2. Points where stresses are computed are 0123 4 – 9. The positive direction is from 9–1 and from OY_1 to OY_2.

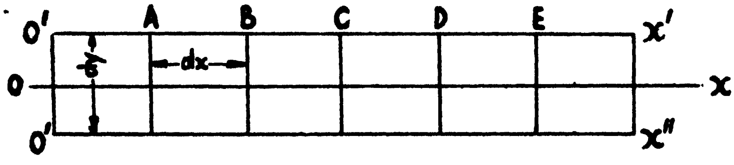

Fig. 8.—Shear difference analysis.

For each section curves of P–Q, and θ are drawn from Figs. 1A and 10, shear computed and plotted from $\frac{P-Q}{2} \sin 2\theta$. A nomogram (Fig. 11) is recommended for this operation.

The sign of σxy is obviously positive, the major algebraic stress being in the first quadrant. This applies to $\tau x_1 y_1$ and $\tau x_{11} y_{11}$ also. A curve is drawn of $\tau x_{11} y_{11} - \tau x_1 y_1$ and as $dx = dy$ numerically that is all that is necessary. It must be noted that in moving from 1–9 dy is negative, so that the curve of $\tau x_{11} y_{11} - \tau x_1 y_1$ must be drawn as a negative value and not a positive value.

As both top and bottom edges are free boundaries and as the stress normal to a free boundary is zero, the stresses at points 0 and 9 are known. Using these, the stress σy at all points is computed. At this stage it is easier to keep the stress in fringe values.

From the curve of P–Q and τxy for the OY section the value of $(P-Q)^2 - 4\,\tau xy^2$ is found and so σx. σx at the free boundaries is the isochromatic value.

Curves of σx and σy are plotted. It is to be noted that in this case the OY axis is used for calculation and not the OX. This is a matter of choice and, if care is taken to notice the effect on signs, will not effect results.

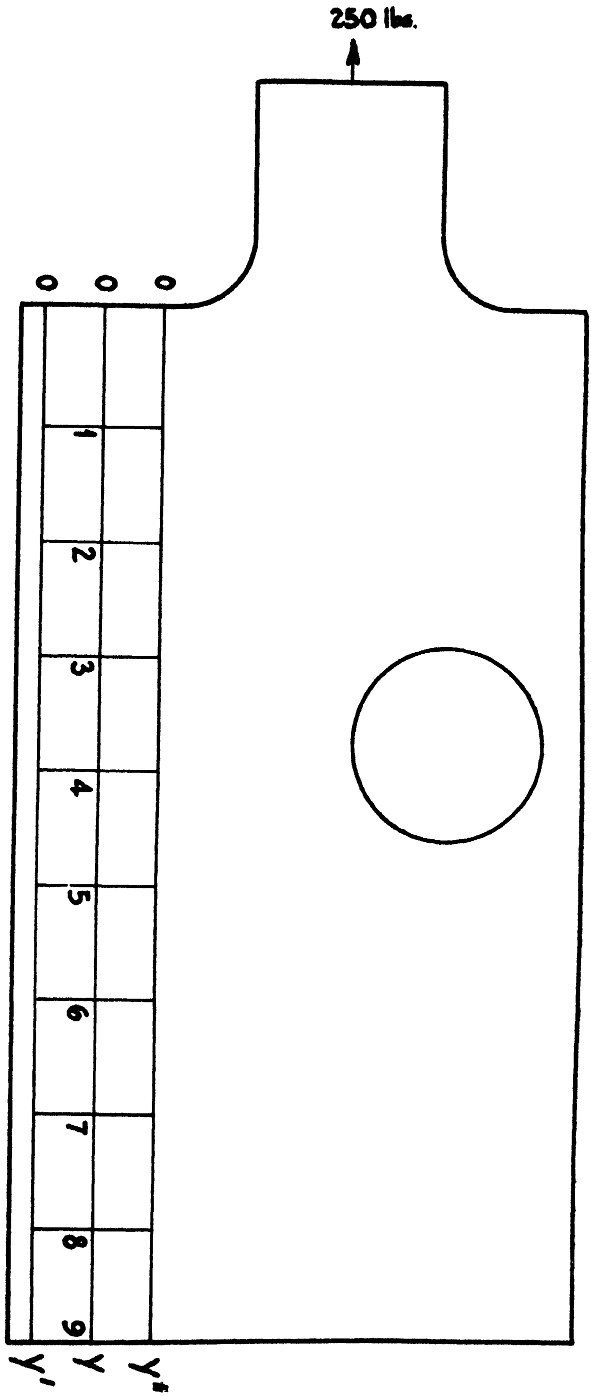

FIG. 9.—Model (showing positions of calculations).

Static Checks.—The area under the shear curve (τxy) is the total shear force across the section OY. This is obviously the same as the applied load, as it is pure shear at this section.

The area under the shear curve has a mean value of 0·976 fringes. The fringe value for Bakelite is 42·8 lb./sq. in./in. thick. The model is 0·284 in. thick.

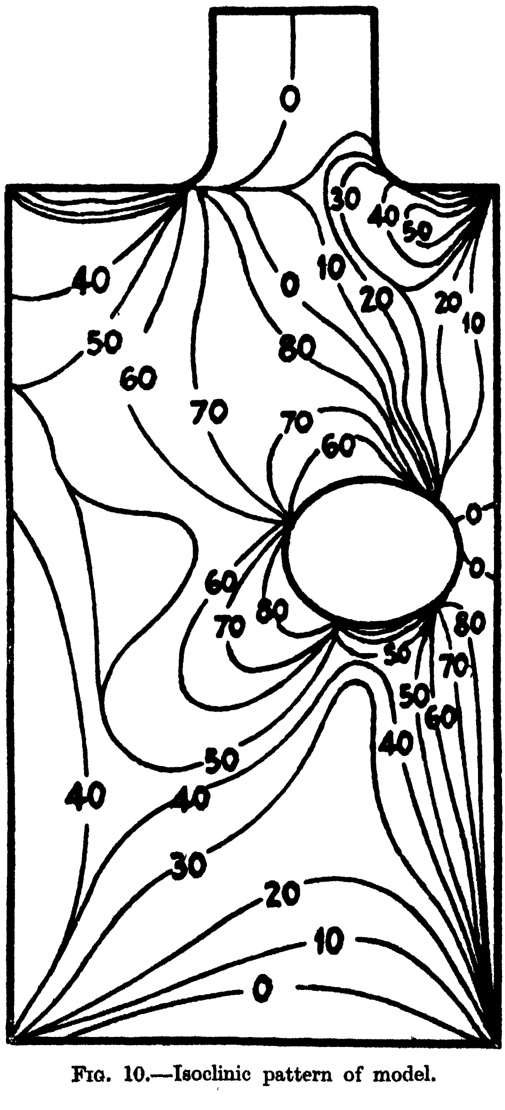

FIG. 10.—Isoclinic pattern of model.

This makes P–Q equal to $\frac{42 \cdot 8}{\cdot 284} \times 2 = 303$ lb./sq.in.

Therefore, as the cross-sectional area is 3·0 in. $\times$ 0·284 in., the applied load was

$$\cdot 976 \times \cdot 303 \times 3 \cdot 0 \times \cdot 284 = 252 \text{ lb. (an error of 0·8 per cent.).}$$

The areas under the shear curves of both OX_1 and OX_2 were also found and from these an applied load of 244 lb. and 252 lb. was calculated. As an added check, the stress σy at point " 0 " is zero, and by calculating along OY a stress of zero at point " 9." is obtained. This is correct, as " 9 " is on a free boundary.

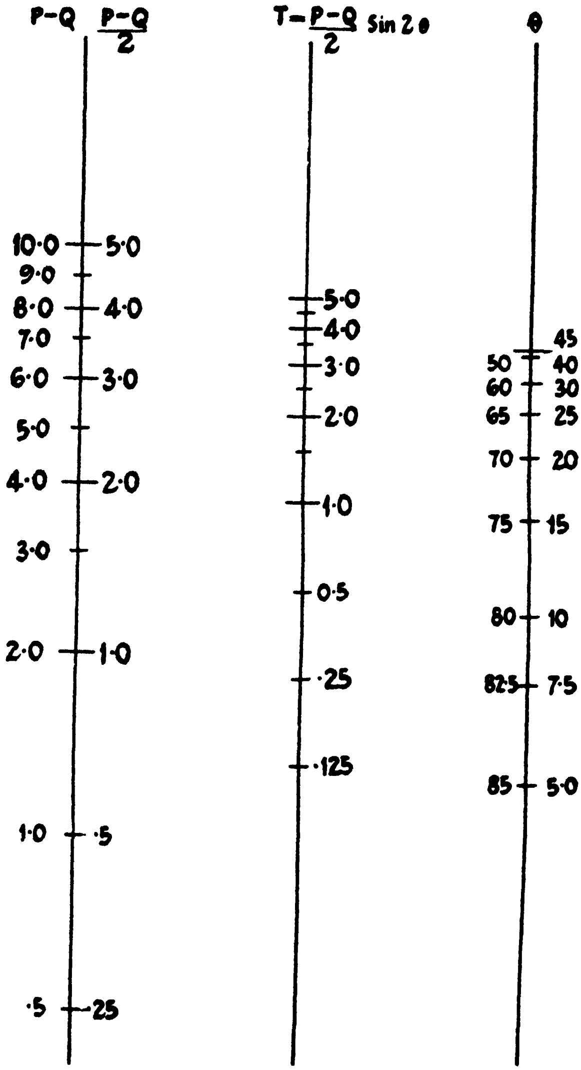

FIG. 11.—Nomogram used to compute shear.

From the nature of the loading the stress is obviously pure shear and so the area under the σx curve is nearly zero, as is to be expected.

The figures in Table II are taken from the graphs $\Delta T = \tau x_{11} y_{11} - \tau x_1 y_{19}$, and $\Delta T \frac{dy}{dx}$ at station 3 is the value of mean ordinate of the curve between stations 2 and 3.

TABLE II

Point.	$\Delta T \frac{dy}{dx}$	σy Fringe.	$(P\text{-}Q)^2$	τxy.	$4\,\tau xy^2$	$(P\text{-}Q)^2 - 4\tau xy^2$	$\sqrt{(P\text{-}Q)^2 - 4\tau xy^2}$	σx Fringe.	σx lb./sq.in.	σy lb./sq.in.
0 ..	0	0	14·1	0	0	0	0	−3·75	−1,135	0
1 ..	−·3	+·3	6·89	1·35	6·76	·13	·36	−·06	+18·2	+91·2
2 ..	−·35	+·65	9·0	1·5	9·0	0	0	+·65	+197	+197
3 ..	−·1	+·75	8·45	1·45	8·45	0	0	+·75	+227	+227
4 ..	+·1	+·65	6·76	1·3	6·76	0	0	+·65	+197	+197
5 ..	0	+·65	4·84	1·05	4·42	·42	·65	0	0	+197
6 ..	0	+·65	3·35	·85	2·88	·47	·685	−·035	−10·6	+197
7 ..	+·1	+·55	1·96	·6	1·44	·52	·72	−·17	−51·7	+166
8 ..	+·35	+·25	·81	·35	·49	·31	·55	−·3	−91·2	+76
9 ..	+·25	0	0	0	0	0	0	0	0	0

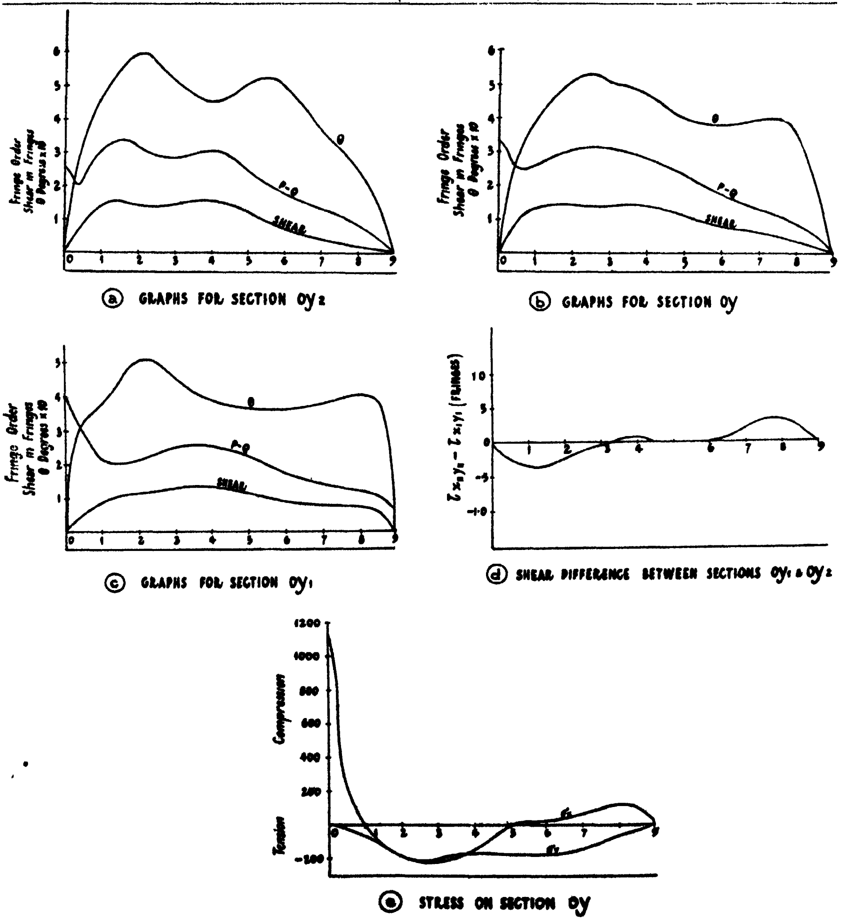

FIG. 12.

CONCLUSION

The photoelastic method is comprehensive and accurate and is ideal for models of large engineering structures. The technique is fundamentally a laboratory one and requires more equipment than for most types of stress analysis. The calculations are simple in comparison with the long mathematical methods of treating indeterminate structures. In general, the engineering designer can be said to have at hand a useful and accurate tool.

ROT-PROOFING OF CANVAS

PRELIMINARY REPORT ON EXPERIMENTS CARRIED OUT IN 1944-45

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Summary

(1) A series of investigations was conducted in order to establish a suitable technique for testing therapeutants used for protecting canvas, cordage, &c., against fabric-rotting fungi.

(2) Isolations from specimens of rotted canvas yielded a number of common mould fungi. From these, *Stachybotrys atra* Corda, an active cellulose-destroying fungus, was selected as the most suitable test organism for the experiments.

(3) A technique was evolved by which treated strips of canvas, both before and after leaching, were inoculated with *S. atra* and held for three to four weeks under optimum conditions of temperature and moisture for growth of the test fungus.

(4) Seven chemicals were tested by the above technique for their efficiency as rot-proofing agents.

(5) Results of experiments are expressed as tensile breaking load of test canvases in pounds.

AT the request of the New Zealand Standards Institute, a series of investigations was conducted in order to establish a suitable technique for testing therapeutants suggested by manufacturers for protecting canvas, cordage, &c., against fabric-rotting fungi. During the course of these investigations seven chemicals at varying concentrations were tested for their efficiency as rot-proofing agents.

ISOLATION OF FUNGI

To obtain a suitable test fungus for the investigations, isolations were made from specimens of rotted canvas obtained from the Pacific war zone, from New Zealand, and from specimens of new untreated material. A number of common mould fungi was isolated, including species of *Alternaria*, *Stemphylium*, *Phoma*, *Penicillium*, *Trichoderma*, *Pleospora*, *Aspergillus*, *Chaetomium*, *Memnoniella*, and *Stachybotrys*. Inoculation tests with these fungi on small pieces of sterilized canvas showed that *Stachybotrys* (*S. atra* Corda) and *Memnoniella* (*M. echinata* (Riv.) Galloway) alone caused appreciable rotting of the fabric. *Stachybotrys* was selected as being the more suitable test organism, owing to the prolific production of dark-coloured spores by which its presence on canvas was easily recognized.

CHEMICALS TESTED

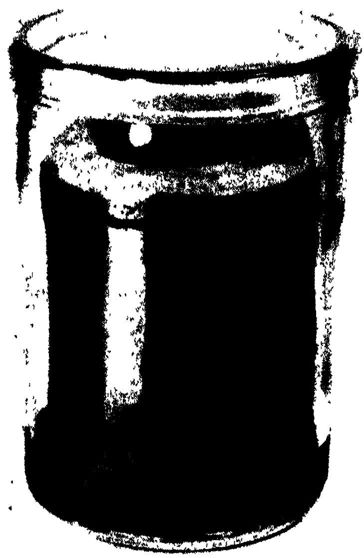
The following chemicals were tested at varying concentrations:—

(1) Sodium salicylanilide (Shirlan W.S.) in water.
(2) Sodium pentachlorphenate (Santobrite) in water.
(3) Phenyl mercuric acetate in water.
(4) Pentachlorphenol in mineral turpentine.
(5) Copper naphthenate in mineral turpentine.
(6) Zinc naphthenate in mineral turpentine.
(7) Copper oleate in mineral turpentine.

Technique

In preliminary experiments, untreated strips of 12 oz. cotton duck were inoculated by spraying with a spore suspension of *Stachybotrys* in water, placed in a saturated atmosphere in glass containers, and kept for four weeks at 27°C. Results indicated that the canvas did not absorb sufficient moisture from the atmosphere to support vigorous growth of the fungus and cause subsequent rotting of fabric. It was apparent that canvas had to be in close contact with a wet surface in order to absorb the required amount of moisture. After further work the following method was evolved and used in all subsequent investigations.

Strips of 12 oz. cotton duck 9 in. long by 3 in. wide, the longest side being cut from the warp of fabric, were sterilized by autoclaving for twenty minutes at 12 lb. pressure. Strips were then dipped in various



[*Photo by L. H. Wright.*

FIG. 1.—Method for incubation of test canvas after tying to porous field pipe. Untreated strip two weeks after inoculation with *Stachybotrys atra.*

therapeutant solutions for one hour and surplus liquid rolled out of the fabric. They were then dried on plate glass at air temperature for twenty-four hours, and placed in a hot-air drier at 45°–50°C. for four hours. Inoculum was prepared by washing spores from four petri-dish cultures of *Stachybotrys* and diluting in 400 ml. sterile water. This was applied to test canvases by means of a de Vilbiss atomizer to give complete coverage without run off. Following inoculation, strips were tied to sterile 4 in. sections of porous, earthenware field pipes 2 in. in diameter. Both pipes and fabric were placed in covered glass jars containing 60 ml. sterile water (Fig. 1) and incubated for four weeks at 27°C. A second spore inoculation was applied after two weeks and water replaced in jars. Finally the amount

of fungous growth was recorded, and samples, after drying, were sent to the Dominion Physical Laboratory, Wellington, for determinations of tensile strength.

Results

In Tables, I, II, and III are given results of tests with the above chemicals at various concentrations. Results are expressed in pounds, representing the mean tensile breaking load of test strips after inoculation and incubation. Means are based on four replicates in Table I and on eight replicates in Tables II and III. Concentrations refer to strengths of dipping solutions.

TABLE I.—EFFECTS OF TREATMENTS ON UNLEACHED CANVAS, EXPRESSED AS BREAKING LOAD IN POUNDS

Treatment.	Concentrations.				
	0·05 per Cent.	0·1 per Cent.	0·5 per Cent.	1·0 per Cent.	2·0 per Cent.
Sodium salicylanilide ..	144	176	384	331	364
Sodium pentachlorphenate	314	299	334	377	250
Untreated canvas ..	315	..	..	..	..
Untreated canvas inoculated	38	..	..	..	..

Difference required for significance at 5 per cent. level=59.

TABLE II.—EFFECTS OF TREATMENTS ON UNLEACHED CANVAS, EXPRESSED AS BREAKING LOAD IN POUNDS

Treatment.	Concentrations.			
	0·01 per Cent.	0·05 per Cent.	0·1 per Cent.	0·5 per Cent.
Pentachlorphenol	112·5	158	275	305
Sodium pentachlorphenate	189	312	310	318
Untreated canvas	315	..	..	..
Untreated canvas inoculated ..	56	..	..	..

Difference required for significance at 5 per cent. level= 12·5.

TABLE III.—EFFECTS OF METALLIC SOAP TREATMENTS ON UNLEACHED CANVAS, EXPRESSED AS BREAKING LOAD IN POUNDS

Treatment.	Concentrations as Percentage Metal in Solutions.					
	0·01 per Cent.	0·05 per Cent.	0·1 per Cent.	0·5 per Cent.	1·0 per Cent.	2·0 per Cent.
Copper naphthenate ..	208	309	297	322	342	358
Zinc naphthenate	113	311	301	321	325	362
Copper oleate	..	..	215	316	323	348
Untreated canvas	315	..	..	..	..	..
Untreated canvas inoculated..	62	..	..	..	..	..

Difference required for significance at 5 per cent. level=30·9.

Discussion of Results

Results set out in Table I indicate that on unleached canvas, sodium salicylanilide gave protection against rotting at concentrations of 0·5 per cent. and upwards, although small scattered colonies of *Stachybotrys* were present on treated material up to a concentration of 1 per cent. without producing loss in tensile strength. Sodium pentachlorphenate was effective at all concentrations used in this test. From the significant loss in tensile strength at 2 per cent. concentration it would appear that in this instance slight damage to fabric had occurred following treatment. Table II shows that effective control of rotting by the test fungus was obtained with pentachlorphenol at 0·5 per cent. concentration, and with sodium pentachorphenate at 0·05 per cent. and upwards. Results shown in Table III indicate that copper and zinc naphthenates gave effective control at concentrations of 0·05 per cent. metal and above, while at 0·01 per cent. concentration the former chemical was significantly more efficient. Copper oleate gave protection against rotting at concentrations of 0·5 per cent. and upwards. In the copper oleate series sparse growth of *Stachybotrys* occurred throughout, and severe bacterial staining was evident at concentrations of 1 per cent. and 2 per cent., although no loss in tensile strength was recorded at these concentrations.

It will be seen from Table III that samples treated with copper and zinc naphthenates and copper oleate at a concentration of 2 per cent. show a significant increase in tensile strength over that of untreated uninoculated samples. This is possibly due to the chemicals causing increased friction between fibres of the material, thus preventing relative slipping when under test.

EXPERIMENTS WITH TREATED CANVAS SUBJECTED TO ARTIFICIAL LEACHING

In experiments described above, treatments were not subjected to weathering, and since leaching is of major importance under field conditions, a series of trials was undertaken in which treated canvas was tested after artificial leaching.

Technique

Canvas, after chemical treatment, was leached by placing 9 in. by 3 in. strips on a wooden frame attached to a bicycle wheel, which was rotated by a finely atomized spray of water directed against canvases. The rate of flow of water was adjusted to approximately 600 ml. per minute, and the wheel revolved once every seven seconds. Leaching was continued over ten three-hour periods, the fabric being dried after each period for one and a half hours in a hot-air oven at 45°–50°C. In preliminary tests, when leached untreated canvas was inoculated and incubated as above, little or no growth of *Stachybotrys* occurred because of leaching of nutrient from the fabric. Further tests were carried out by placing leached untreated canvas on top of canvas which had been inoculated and incubated for seven days. As in both methods growth of the test fungus and subsequent rotting were unsatisfactory, they were abandoned. Sterile water was replaced in the jars with sterile nutrient solution containing 0·5 g. KNO_3, 0·1 g. K_2HPO_4 and 0·02 g. $MgSO_4$ to 100 ml. of water. The nutrient reduced time of incubation to three weeks, and resulted in almost complete loss of tensile strength in untreated leached canvas, owing to rapid growth of the test fungus.

Results

In Tables IV and V are given results obtained with leached and unleached treated canvas after inoculation and three weeks incubation with nutrient solution. Each figure represents a mean of six replicates. A preliminary test with untreated uninoculated canvas showed no significant difference in tensile strength between leached and unleached samples.

TABLE IV.—EFFECTS OF TREATMENTS ON LEACHED CANVAS, EXPRESSED AS BREAKING LOAD IN POUNDS

Treatment.	Concentrations.											
	0·01 per Cent.		0·05 per Cent.		0·1 per Cent.		1·0 per Cent.		2·0 per Cent.		3·0 per Cent.	
	Unleached	Leached.	Unleached.	Leached.	Unleached	Leached.	Unleached	Leached	Unleached	Leached	Unleached.	Leached.
Sodium salicylanilide ..	..	.	.	..	.	..	..	..	323	84	360	169
Sodium pentachlorphenate	..	..	..	.	.	..	331	130	343	172	..	144
Pentachlorphenol ..	..	..	..	..	..	.	351	182	339	271	338	347
Phenyl mercuric acetate ..	352	254	329	285	322	346	.	..	..	.	..	..
Untreated unleached canvas	354		..		..		..		..		..	
Untreated leached and inoculated	38		..		..		..		..		..	

Difference required for significance at 5 per cent. level = 30·5.

TABLE V.—EFFECTS OF METALLIC SOAP TREATMENTS ON LEACHED CANVAS, EXPRESSED AS BREAKING LOAD IN POUNDS

Treatment.	Concentrations as Percentage Metal in Dipping Solutions.							
	0·1 per Cent.		0·5 per Cent.		1·0 per cent.		2·0 per Cent.	
	Unleached	Leached.	Unleached.	Leached.	Unleached.	Leached.	Unleached	Leached.
Copper naphthenate	363	346	357	358	325	356	366	376
Zinc naphthenate	346	122	362	279	357	349	388	358
Copper oleate..	230	84	347	303	353	360	348	371
Untreated unleached canvas ..	351		..		..		..	
Untreated leached and inoculated	38		..		..		..	

Difference required for significance at 5 per cent. level = 41.

Discussion of Results

Figures set out in Table IV reveal that leaching of canvas treated with sodium salicylanilide and sodium pentachlorphenate has resulted in greatly increased loss of tensile strength after inoculation with *Stachybotrys* even at the highest concentration employed. With pentachlorphenol, results suggest that a 3 per cent. concentration would be necessary for adequate protection against rotting. Phenyl mercuric acetate showed significant loss in tensile strength at concentrations of 0·01 per cent. and 0·05 per cent.

after leaching, and also a slight loss due to treatment on unleached samples at 0·1 per cent.

Results in Table V indicate that on canvas treated with metallic soaps, leaching occurred to a lesser extent than with the other chemicals tested. In the copper naphthenate series leaching was negligible even at the lowest concentration employed, while in the zinc naphthenate and copper oleate series severe loss in tensile strength occurred on leached canvas at 0·1 per cent. and significant loss at 0·5 per cent. concentrations.

FURTHER TESTS

Further comparative experiments with *Stachybotrys atra* and two fabric-rotting test fungi obtained from the United States of America, *Chaetomium globosum* and *Metarrhizium glutinosum*, are being carried out to ascertain their relative rotting properties and also their reaction to the rot-proofing chemicals under test.

ACKNOWLEDGMENT

Thanks are due to officers of the Dominion Physical Laboratory, Wellington, for carrying out tensile-strength determinations of test canvases used in the experiments.

LUMINIZING ARMY RADIO EQUIPMENT

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Summary

The New Zealand Ministry of Supply requested the Department of Scientific and Industrial Research to undertake luminous painting of meter scales for incorporation into radio transceivers for tropical use. Experiments were carried out both with activated fluorescent coated dials and those with radium activated paint. The latter proved simpler and more effective in operation, but greater consideration had to be given to staff control and working conditions owing to the highly toxic nature of the compounds used.

After suitable premises were established, other developments were undertaken utilizing similar materials. Luminous rifle sights, jungle-trail markers, and tuning controls were developed to the prototype stage, fully tested, and then complete data for their manufacture were passed on to the Ministry of Supply.

At a later stage tests were also conducted on the effectiveness of varying methods of tropic proofing in conjunction with the Plant Diseases Division, Plant Research Bureau, Department of Scientific and Industrial Research. Several types of fungicides were investigated.

In eighteen months, over 400 g. of radium activated luminous powder were used for the treatment of fourteen thousand milliameter dials. Routine testing of dial painters showed that the close contact with this highly radioactive material had not affected any to a measurable degree.

REASONS FOR ESTABLISHMENT

IT was decided in 1943 that in future all field radio equipment must have vital controls painted with luminous or fluorescent compounds for night visibility.

At the time, The Radio Production Department of the Ministry of Supply, was organizing the manufacture of radio equipment for the Forces in Burma. The ZCI, Mk. I, transceiver was the essential part of this programme. About the end of 1943 an improved model, the Mk. II, was in the prototype stage, and the author was asked to investigate the supply of luminous materials and their application to the meter and tuning controls of this set. After experiments with the fluorescent and phosphorescent compounds available locally, it was decided that only self-luminous paint, activated with radium or mesothorium, would be reliable in the tropics.

An order was immediately placed in the United States for a quantity of radium activated compound, together with the necessary mixing media and application equipment for all types of work. Steps were then taken to facilitate erection of premises for storage and application of the compound and at the same time to investigate the position in regard to painting staff.

CHOICE OF LOCATION

As a large part of the final assembly of ZCI sets was done in Auckland it was considered that this city would be the logical place for handling the work. However, as the Dominion Physical Laboratory at Lower Hutt had large grounds where premises could be erected at a safe distance from well-organized workshops and laboratories, this site was chosen. It proved a wise choice later, as it would have been impossible, without the resources of this Department, to erect premises elsewhere so quickly or generally to facilitate the work. The author was then seconded to the staff of this organization. Members of the Dominion Physical Laboratory executive staff soon arranged for erection of premises, and in two weeks after choosing the site in December, 1943, the first buildings were ready to receive the radium compound for storage.

TYPE OF BUILDINGS CHOSEN

Prefabricated Army huts 20 ft. long by 8 ft. wide were chosen as being most suitable. When their use was over, they could be easily moved or destroyed, if contaminated. Three such huts were obtained with two smaller structures built in close proximity. The three 20 ft. by 8 ft. huts were fitted out as follows :—

Hut No. 1 was lined with three-ply board heavily coated with cream Dulux. The floor was covered with linoleum sealed at the joints and to the base of the walls. Lighting was flush with, and concealed above, the ceiling. Five feet of floor space were walled off to give a porch for washing and clothes storage. Two ventilated plate-glass painting cabinets and one large drying cabinet were installed in the working space of this hut. Cabinet supports and chairs were of chrome-plated steel tubing, and all equipment was constructed in accordance with latest overseas practice.

Hut No. 2 was lined out with Pinex wallboard also coated with cream Dulux, and was covered 4 ft. up from the floor with a layer of white Sanitas cloth for easy cleaning. A small administrative office was walled off 5 ft. from the end of this hut. The floor was covered with linoleum and sealed as in Hut 1. A black " vitrolite " work bench supported by detachable chrome plated supports was placed along one wall of the work-room. Chairs were similar to those in Hut 1. Low-voltage fluorescent light fittings were installed, suspended from the ceiling by movable cords. They could be raised flush with the roof or lowered to within 18 in. of the work-bench.

Hut No. 3 was lined to half its length. The Pinex-lined portion was used for "tropic-proofing" of meters, while the unlined part had benches and shelves for use as a store and packing room. A large steel vacuum cabinet was installed in the tropic proofing room as well as a ZCI, Mk. II, transceiver for testing meters under service conditions. Other electrical testing equipment was also kept in this hut away from possible dust contamination.

FIG. 1.—Ventilated painting cabinet in painting hut, showing waste receptacle, meter dials after painting, and painting equipment.

The paint storage hut was 8 ft. long by 6 ft. wide, lined with Dulux-coated ply-wood and built at a safe distance from the nearest working-room. The floor was of smooth concrete "coved" into the base of the walls and sloped down to one corner for drainage. A copper pipe drilled for water spray was carried round the bottom of the walls, 6 in. above the floor. The valve controlling the flow of water was outside. The hut did

not have windows. A 150-watt filtered ultra-violet lamp and a normal filament lamp were recessed into the centre of the ceiling. Supported on a stout concrete pillar 4 ft. from the centre of the floor was a radium storage safe with 2 in. walls of welded steel. The door had a rubber seal which prevented escape of radon gas when not in use. When the door of the room was opened a switch connected to a suction fan outside caused a current of air to be drawn through the safe.

There was a small dressing-room offset from Huts 1 and 2 which contained a hand basin with hot and cold water connected. Clothes-racks were made for street clothes, and a toilet was built off it with an inside connecting door.

INSTALLATION OF EQUIPMENT

The Main Ventilation System.—The huts used for luminous painting and adjustment of meters, as well as the paint storage hut and dressing-room, were heavily ventilated by air sucked outwards. A large suction fan capable of removing 6,000 cubic feet of air per minute was housed 30 ft. behind the buildings. Large ducts led from the fan-house to exits flush in the walls and directly in front of all working positions. Smaller ducts removed air from the painting cabinets, above the hand basins and from the drying cabinet. Ingress of air was made through large ducts into each hut placed in positions to reduce direct draughts. They were heated in winter. In all cases the air-flow velocity and volume were measured, and after calculation found to be 200 per cent. greater than required for minimum safety of operators.

The exit of air at the fan-base was over a large revetted pit 6 ft. in diameter and depth. A baffle was attached to the air exit, which was controlled normally by a cable led up to the entrance of the huts. The fan ran continuously night and day so that no compound could be blown back into the work places when the staff was absent.

Equipment for Painting.—All radium compound was mixed into paint in the paint-storage room over the wet concrete floor. Palettes were made from 3 in. plano-convex lenses with ½ in. holes bored into the tops of the convex curvatures.

The powder was sent into the painting hut combined with varnish only. It was thinned as required, when painting was in progress. As all mixing of dry powder was done under filtered ultra-violet light there was little likelihood of dry compound being dispersed into the painting hut, or its surroundings.

Paint was applied to equipment with wooden meat-skewers impregnated with phenolic resin. They were cheap and were disposed of without cleaning after each working period.

Rubbish Containers.—Used paper towels, paint applicators, and all refuse were placed in paper bags for disposal. The open bags were mounted in wire frames supported by uprights from a circular wire base. These refuse bags were burnt daily at the back of the compound, the ash being damped down and placed in drums for disposal.

HEALTH PRECAUTIONS FOLLOWED

All processes involving hazards were studied by Dr. E. R. Cooper, the Director of the Dominion Physical Laboratory, and Dr. Bastings in conjunction with the author, and approved by the Department of Health.

The routine finally evolved was as follows :—

(1) Surgeon's gowns were donned for all work in connection with luminous compounds, and all personal jewellery, watches, and ornaments were placed in a cupboard. Operators hung their gowns in specially marked cupboards in the porch when leaving for meals or visiting the laboratory, and on returning donned fresh gowns from other cupboards.

At the end of work periods or when leaving the painting hut for any reason, the operator had to wash the hands and have them examined under ultra-violet light for traces of compound. Should washing with soap and water not be effective, use was made of a special hand cleaning solvent. This was not used indiscriminately however, owing to the danger of causing dermatitis.

(2) Vitrolite work benches and shelves were cleaned every day with damp paper towels. Floors were mopped daily with damp mops and cleaned weekly with copious quantities of warm water. Once a week all benches and chairs were dismantled, taken outside, and hosed down.

(3) At regular intervals during the week a portable ultra-violet lamp was carried round all working positions, wash basins, and painting cabinets. Minute particles of dry compound or paint spots were easily visible by their intense fluorescence, and these inspections showed where any accumulation of radio-active material had taken place. The particles were then removed with damp paper towels.

Health Tests of Operators.—During the first eight months of operation, blood counts of all operators were taken monthly. This procedure was discontinued when apparatus was made available in the Travis Radio-Physics Laboratory for accurate measuring of the radon content of operators' breath. Litre breath samples were sent monthly to the Christchurch Laboratory with the help of Dr. Bastings and Mr. G. E. Roth. In no case did the fixed radium burden, calculated on exhaled radon, exceed the minimum safe tolerance of 0·1 microgram per person.

At the completion of twelve months' work operators in close association with radio-active material were given a holiday of four weeks. Whenever the weather permitted, assembly work was carried out in the open air in a sheltered sunny position.

PRODUCTION WORK CARRIED OUT FROM JANUARY, 1943, TO JUNE, 1945

Luminizing Meter Scales.—Painting meter pointers and scales of the first 10,000 meters required greater care and precision than the later contract of 4,000. The moving coils of all meters in the first contract had to be re-adjusted for balance owing to the additional weight of paint on the system. This was tedious and exacting work. At the beginning over 10 per cent. had to be rejected, but six months later only 4 per cent. were lost.

After painting, rebalancing and testing, they were given a flash dip of hot cerise wax to prevent damage by humidity later.

When the last 4,000 were luminized it was decided that recalibration from micro-ammeters to milliameters should also be done by the luminizing section. This necessitated the winding and incorporation of 4,000 constantan resistances for shunts. Soldering them in place and final calibration was also a rather tedious task, but was accomplished ahead of schedule.

The chief difficulties in the manufacture and calibration of shunt resistors was shortage of man-power and lack of jigs and calibration set-up. Wherever short cuts could be found they were put into use immediately.

The constantan resistance wire was wound on a large wooden mandrel, the circumference of which was the exact length of the resistance. A V slot was made along the length of the wooden cylinder, and when the

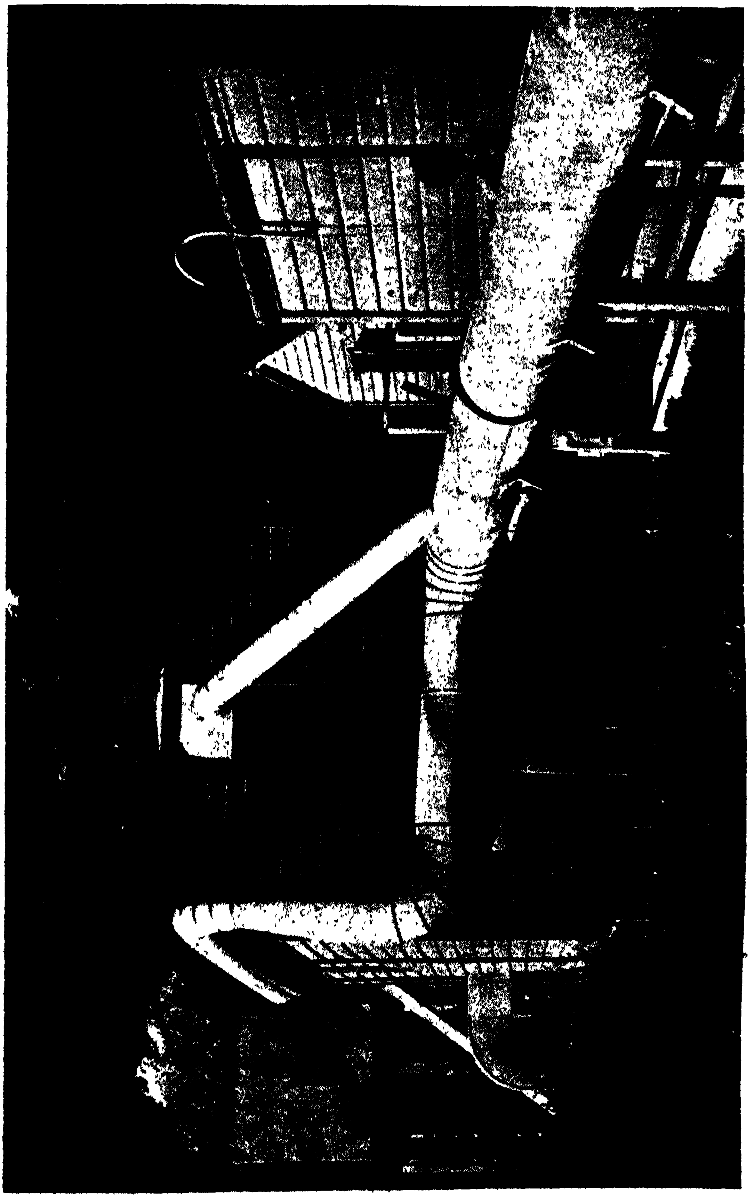

FIG. 2.—Ventilation duct leading from painting hut to fan house. Air inlet duct on the left side of this hut is also visible.

requisite number of turns was cut they produced pieces of wire of exact length. Over fifteen hundred lengths were cleaned, tinned, and cut per hour by this method. Variation of $\frac{1}{16}$ in. in the length would have made the wire pieces unsuitable for resistances.

Luminous Trail-markers.—A sample marker was obtained from the American manufacturers in 1943. On investigation it was found that supplies of a modified type could not be obtained in time for the landings of New Zealand Forces in the Pacific Islands. When the sample was analysed for production locally, immediate steps were taken to produce 500 of the modified type.

The marker consisted essentially of the following parts :—

(1) A metal capsule with turned up lip :

(2) A concavo-convex methacrylate perspex moulded "bulls-eye," coated on the inside with a thick layer of self-luminous paint and sealed behind with a celluloid cap :

(3) The luminous capsule was then inserted in the metal backing and the whole placed in a steel jig to turn down the metal lip and seal in place :

(4) The edges were sealed with Glyptal varnish to prevent moisture penetration.

At a later stage in the war similar types of luminous markers were used with success in the night landings on the beaches of Normandy. Combinations of markers in prearranged figures conveyed information to the attackers without being visible to the enemy.

Development of Luminous Rifle-sights.—These consisted of fore and back sight attachments containing small luminous capillary tubes tunnelled inside. There were visible to the marksman, but not to the enemy.

At first, small painted strips of luminous material were applied to the fore and back sights of standard rifles. These were tested on the rifle range at a New Zealand Army training establishment by qualified riflemen. Various backgrounds, degrees of visibility, and other factors were studied and tabulated. When it was definitely established that such a device could make for aiming improvement in half-lights, the project was continued.

With the help of small-arms specialists for testing and criticism at each stage, suitable attachments were developed, tested, and produced to the prototype stage. Blue prints and samples were then passed on to the Army authorities.

Luminous Radio Dials.—As over twenty thousand radio dials required to be painted with luminous compound, it was suggested that experiments should be made to find an easier method than the conventional hand painting of figures and graduations, which would require more than 10,000 man-hours. Experiments in moulding dial plates with clear plastic were commenced. The graduations and figures were raised on the back portion of the dial and coated with black ink. Behind them and attached to the steel panels were small polystryrene windows, each containing a sealed layer of radio-active paint on its reverse side.

On turning the dial in the dark, figures and graduations could be easily read in front of the luminous area. The black cursor on this window was lined up with the normal one used for daylight sending.

This method proved very useful in making dial markings visible on small, light-weight battery operated transceivers, where the saving of several milliamps current for dial-lamp operation was extremely valuable.

This method of luminizing tuning dials required no tedious hard work. Samples and the prints were forwarded to the Ministry of Supply, and to overseas signal development authorities for manufacture and incorporation.

Tropic Proofing of Meters—In common with all other components of the ZCI, Mk II, wireless set, it was decided that meters should receive attention for later effects of tropical humidity

At first the joint between the bakelite backing and the case was sealed with Glyptal pigmented varnish Owing to the adhesion of the seal, future opening of meters became impossible, so wax was tried It was found, from watching moisture indicator strips inside the meters, that the wax covering gave much better protection from moisture absorption through the pores of the bakelite case Comparative tests by this method were made with Glyptal sealing of all openings, complete covering by varnish and total immersion in wax Meters were tested in high humidity conditions and

FIG. 3—Completion of a batch of meters ready for testing in tropic proofing hut.

weighed before and after for increase in weight by absorbed moisture As the wax dipping process left no doubt as to efficiency, this method was adopted for 12,000 meters

Wax-fungicide Tests—When wax impregnation was being tested, small samples were impregnated with varying percentages of Shirlan Santobrite, and other reputable fungicides These samples, along with controls, were forwarded to the Plant Diseases Division, Plant Research Bureau, Department of Scientific and Industrial Research, Auckland, for culture of fungi as found in the tropics It was shown conclusively that the wax itself would not support fungal growth, but should colonies become established of their own accord, 0·5 per cent concentration of Shirlan would prevent further growth Reports of these tests were disseminated to radio manufacturers through the Radio Controller

CONCLUSION

Although no fundamental changes were made in the methods of application and use of radio-active luminous materials, it was shown that by accurate scientific control and method, results equal to overseas practice could be obtained in New Zealand. As the whole programme was of high priority, every endeavour was made to facilitate production, and many hours of overtime were worked. Comfortable surroundings, even if of a temporary nature, had definite effects on working speed. As extreme caution, method, and cleanliness had to be practiced for health reasons, this no doubt reacted beneficially in the general quality of the work. After the initial period, few rejections were made on the manufacturers' assembly lines.

Complete co-operation with the Department of Health with regard to operating conditions, and welfare of employees was maintained at all times. No project involving the use of such quantities of unfixed radio-active material had been undertaken before in New Zealand, but it is obvious from the health records of operators that the precautions were effective.

With the importance of radio-active materials becoming so general in matters of warfare, the operating conditions of this project may be of value in the future should further urgent production work be undertaken in New Zealand at any time.

ACKNOWLEDGMENTS

The author is extremely indebted to the Director of the Dominion Physical Laboratory, Dr. E. R. Cooper, and to Mr. G. E. Roth, of the Travis Radio Physics Laboratory, for their ready help at all times and for their advice for safeguarding the author's and his staff's health. Time was spent much in excess of that required by ordinary routine, and helped to relieve any feelings of anxiety by women workers of future health troubles.

REFERENCES USED IN STUDY AND OPERATION OF LUMINIZING WORK

(1) *U.S. Federal Specification TTR 58,* "Radioactive Luminous Compound."
(2) *U.S. Bureau of Standards Handbood H 27,* "Safety Precautions in Handling Radium Luminous Compounds."
(3) *British Factories (Luminizing) Health and Safety Provisions.* Order 1942 dated April 1st, 1942, No. 703.
(4) United States Radium Corporation: Personal communication dated July, 1943.
(5) EVANS, R. D. (1943): "Radium Poisoning." *Journal of Industrial Hygiene 25.*
(6) PATTERSON, WELSH, and HIGGINS (1917): *Proc. Physical Society, London, 29.*
(7) MATTIELLO (1943): "Protective and Industrial Coatings," Chap. 22, Vol. 3.

RADON MICRO DETERMINATION BY THE CURTISS-DAVIS α-PARTICLE COUNTING METHOD

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[Received for publication, 20th August, 1945]

Summary

Modifications of the design and of the routine operation of a radon micro determination equipment, based on the Curtiss-Davis α-particle counting method, are described.

WHEN large numbers of dials and indicators for the Armed Forces in the Pacific had to be marked with radioactive luminous paint it became necessary to ensure the safety of the workers engaged in the luminizing process. Elaborate preventive and diagnostic measures were adopted, which are being described elsewhere. The present paper deals only with the equipment used for the routine examination of the exhaled breath of the "luminizers" for its content of radon gas. The aim of these examinations is the detection of ingested or inhaled radium at the earliest possible moment. Since the safe limit of radon contained in one litre of exhaled breath under certain sampling conditions has been set at 10^{-12} curies of radon(1, 2, 3), occupying less than 10^{-12} cu. mm. and weighing $6{\cdot}5\times10^{-18}$g. a micromethod of radon determination had to be used.

A survey of the recent literature on such methods(4, 5, 6, 7, 8, 9, 10, 11, 12, 13) and on the evaluation of the radium content of the human body from combined radon- and γ-ray measurements(2, 3, 14, 15) led to the adoption of a counting method first proposed by Curtiss and Davis(13). A plant based on the Curtiss-Davis principle was designed and set up at the Dominion X Ray and Radium Laboratory at Canterbury University College, Christchurch (see Figs. 1, 2, 3, and 4).

In the course of the design, test, and routine operation of this plant it was found necessary to depart from the originally described equipment, both in the chemical and the electronic sections of the plant. Some modification of the routine procedure for the measurement had also to be made. The following notes are confined to a description of the modifications of the equipment originally given in Curtiss' and Davis' paper, and only design data not previously published will be given.

The present equipment can be used for the measurement of radon from either gaseous, liquid, or solid samples. The provision of three reflux coolers and liquid sample flasks (S_1, S_2, S_3 on Fig. 1) allows for the ready use of one or two standard Ra-solutions, while the flasks and reflux coolers not permanently used for standardization are available for liquid samples or for solid—*e.g.*, rock—samples treated by the carbonate fusion method. This arrangement makes it possible to use the present plant without any alteration for a planned survey of the radioactivity of New Zealand waters, while at the same time allowing its use in conjunction with a direct fusion furnace(4) which can be connected at 2 instead of the breath-sample flask U as shown in Fig. 1. The five Ra-standard-solutions used contain 10^{-10}, 10^{-11}, 10^{-12}, 10^{-13}, 10^{-14} curies per millilitre respectively,

and were prepared by progressive dilution of a United States Bureau of Standards liquid Ra-standard containing 0·1 μg. of Ra, using the flasks visible beneath the reflux coolers and nitrogen and water distribution

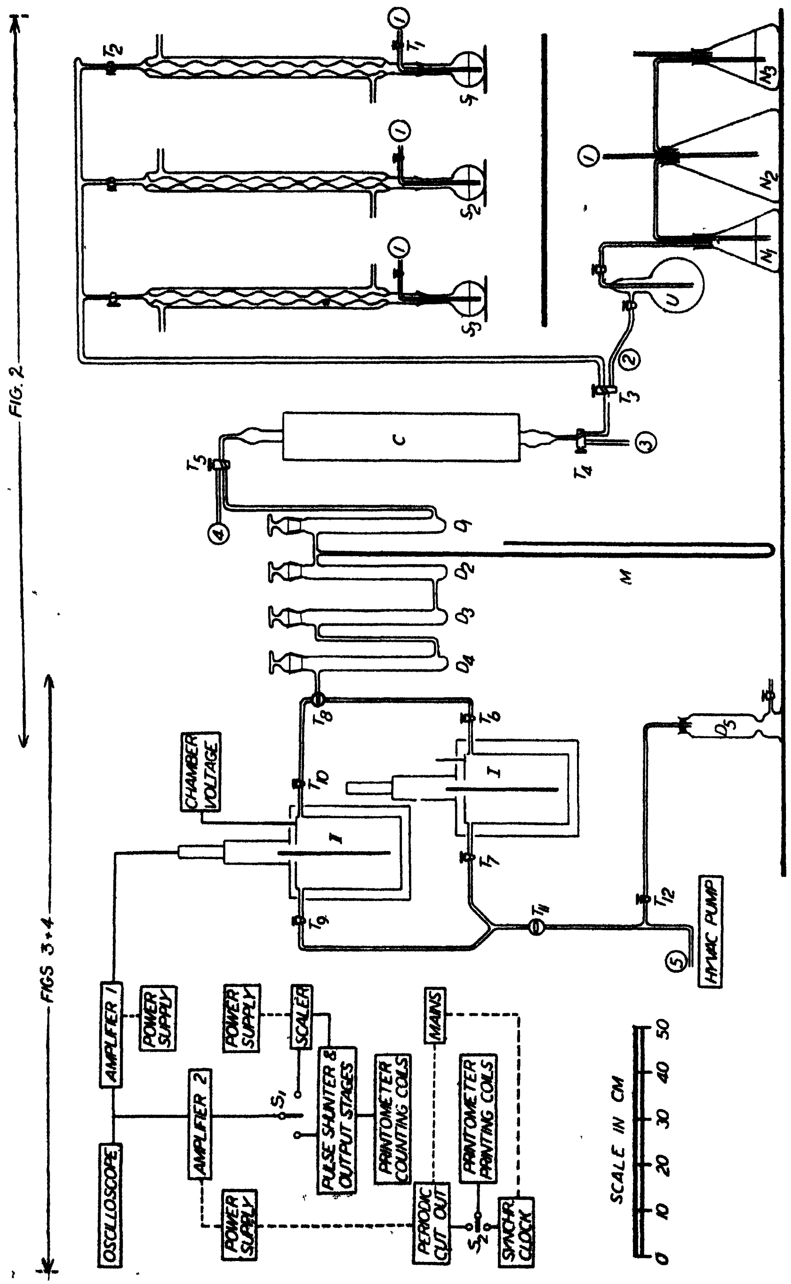
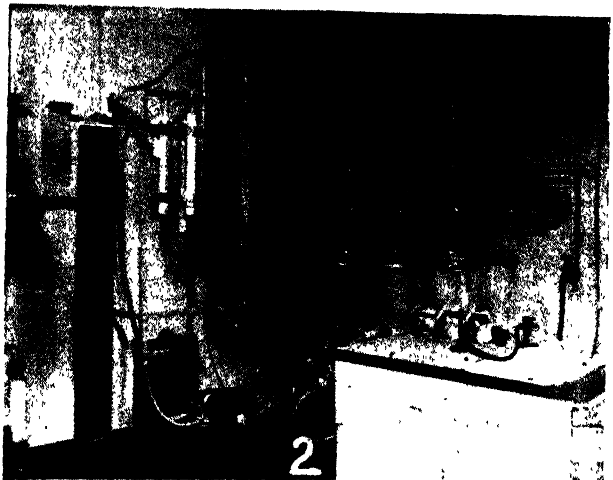
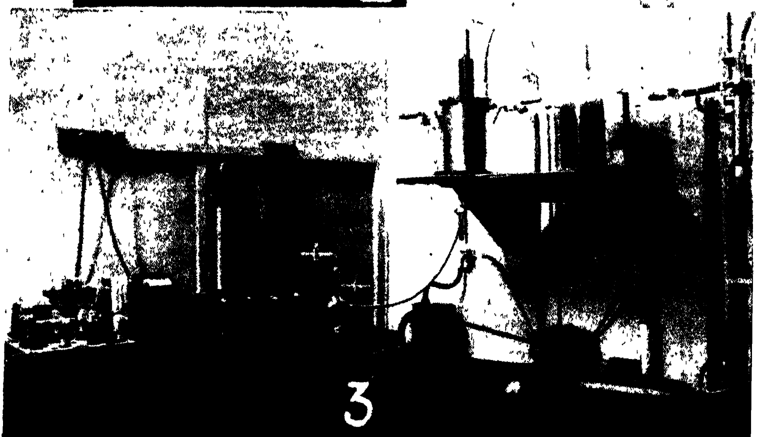


FIG. 1.—Schematic lay-out of the entire plant. The chemical section is drawn to scale. The electronic part of the equipment is shown as a block diagram. The markings at the top of the drawing indicate the equipment covered in Figs. 2, 3, and 4.

lines in Fig. 2. The flasks S_1, S_2, S_3, are usually filled with not more than 100 ml. of liquid. The 1 l. Pyrex flasks used for collecting the breath-samples are shown in Figs. 1 (U), 2, and 3.





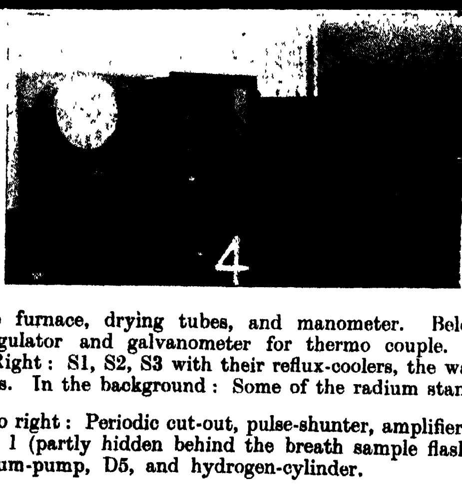


FIG. 2.—Left: The furnace, drying tubes, and manometer. Below the furnace: temperature regulator and galvanometer for thermo couple. Centre: breath sample flask. Right: S1, S2, S3 with their reflux-coolers, the water and nitrogen distribution lines. In the background: Some of the radium standards-containers.

FIG. 3.—From left to right: Periodic cut-out, pulse-shunter, amplifier 2, power-supply, scaler, amplifier 1 (partly hidden behind the breath sample flask), the ionization chambers, vacuum-pump, D5, and hydrogen-cylinder.

FIG. 4.—Printometer, oscilloscope, and output-stage.

A convenient and very fine adjustment of the rate of flow of the tank-nitrogen used for carrying the radon into the ionization chambers is made possible by using a differential rate of flow and pressure indicator, consisting of N_1, N_2, N_3, connected to the nitrogen supply line from the tank at 1 (in Fig. 1, bottom).

It was found that, in addition to the original two drying tubes, provision for the removal of CO_2 and for further drying of the gas had to be made if the plant was to be used for daily routine work. The drying tubes (diameter 30 mm., length between intake and outlet about 25 cm.) are filled as follows: D_1 with $CaCl_2$; D_2 with indicating silica gel.; D_3 with "Sofnolite" (an indicating CO_2 absorber); D_4 with P_2O_5. The arrangement of the drying tubes in pairs behind each other on the mounting rack is shown in Fig. 2.

The two ionization-chambers, I and II, shown in Fig. 3 are provided to enable continuous operation of the plant and can be connected alternatively to D_4 by T_8. One of the ionization-chambers was made of copper, the other of steel. The background counts of the two chambers were 198 and 132 counts per hour respectively. Polystyrene was used as insulation throughout, and the intake and outlet glass-tubes were sealed to the meta chambers by "Plicene" cement. The chamber-voltage was set to 800 volts and was found to be not critical. While operating the plant with its two ionization-chambers and various input tubes to amplifier 1, spurious pulses of reversed polarity were observed. Careful attention to the insulation of the ionization-chambers, and judicious selection of the input-tube (a "Philco" type 38 tube is being used) eliminated this effect.

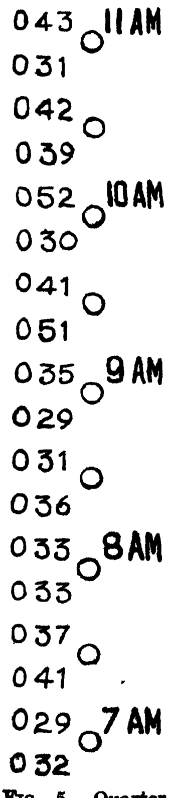


FIG. 5.—Quarter-hourly records of background-counts.

The following observations were made regarding the routine procedure for the operation of the plant. Whenever the plant had been idle for any length of time (exceeding, say, one day) it was found necessary to discard one nitrogen (background) filling in order to make sure that radon, accumulated within the system over the considerable amount of drying agents and copper, was completely removed. Before adopting this procedure the background counts were found to vary considerably, in some proportion with the time elapsed between successive fillings. It was also found that the copper used for filling the furnace tube C (short lengths of hard drawn wire, about ½ in. long) required hydrogenation at intervals considerably shorter than indicated by Curtiss and Davis.

In the design of the electronic part of the equipment it was possible to replace the original traffic-recorder and the Strobotron output stage by a printometer and a conventional output power stage. The traffic-recorder, although printing the total number of counts at hourly intervals, continues adding these numbers. The hourly number of counts has therefore to be found as the difference of two successive numbers printed on the recording tape. The printometer used with the present equipment resets itself automatically to zero after printing at predetermined intervals the number of pulses during each of these intervals. A record of the background count, printed at quarter-hourly intervals, is shown in Fig. 5. The complete circuit diagram of the electronic part of the equipment is given in Fig. 6 omitting only the conventional parts of the circuit—*i.e.*, the power supplies,

the oscilloscope, the "scaler," and amplifier 1, which is based on Waddell's(16) original circuit. It was found that the lack of feedback-stabilization in the first

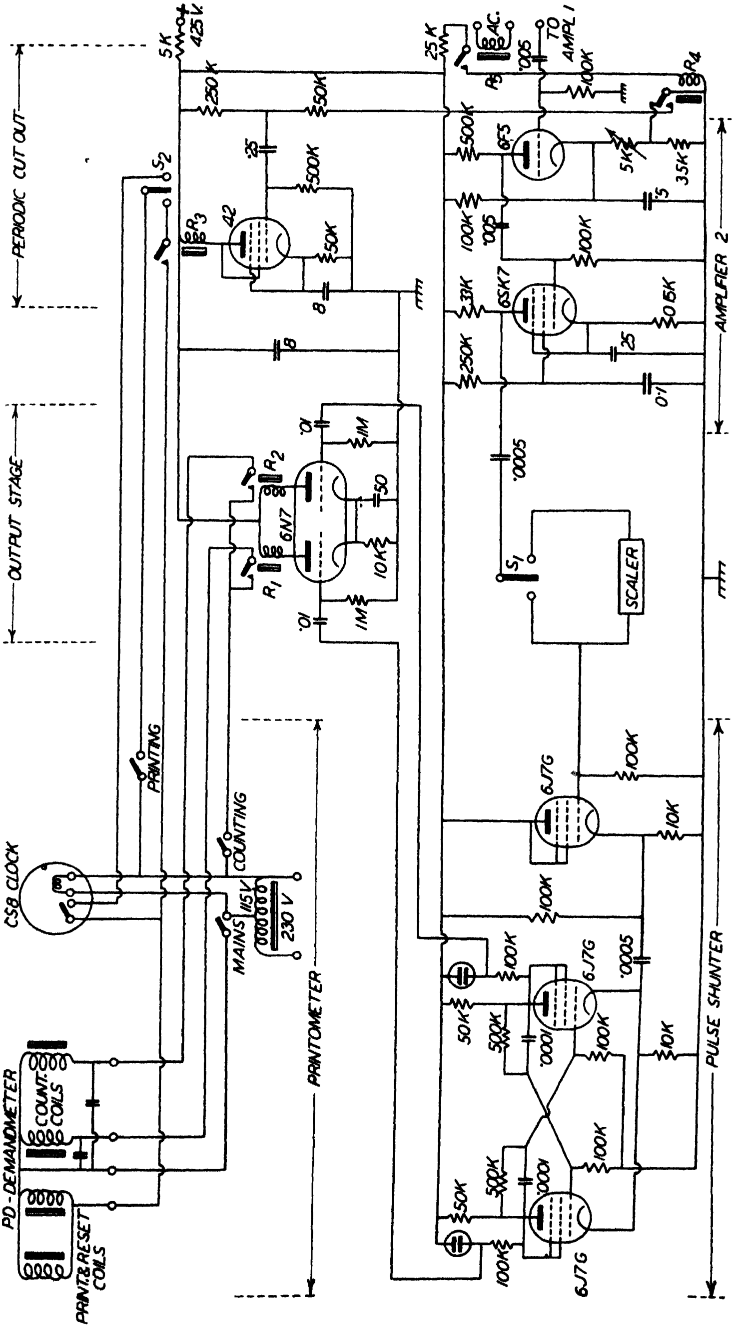


FIG. 6.—The circuit diagram of the electronic part of the equipment. All capacities are stated as μF.

stage of this amplifier resulted in a slight dependance of the counting rate on the filament voltage. A modification of this circuit as suggested by Zagor and Valente(17) should overcome this disadvantage.

The circuit diagram of Fig. 6, read together with the block diagram on Fig. 1, shows that the output of amplifier 1 is fed to the oscilloscope and to amplifier 2. Adjustment of the cathode resistance of the input stage of amplifier 2 enables a close and accurately reproducible discrimination between the noise level and the smallest pulse size admitted to the successive amplifier stages. The output of amplifier 2 can be fed through switch S_1 either directly or through a "scaler" to the "pulse-shunting" stage.

The "scaler" consists of a variable number of identical, series-connected "scale-of-two" units. Any group of "scale-of-two" units, in any required number, can be used in this stage. The "scaler" used in the present equipment (four units of which are shown in Fig. 3) is basically similar to the "pulse-shunter" circuit.

The mechanical construction of the printometer requires that successive pulses must be fed alternatively to two different counting coils. It was therefore necessary to provide a stage which will "shunt" successive pulses into two separate output amplifiers. One type 6N7 tube has been found fully adequate for the output stage, actuating the printometer counting coils through the relays R_1 and R_2 (STC relay, BPO ·3000 type). The printing and resetting coils of the printometer can be connected with S_2 either to a synchronous clock, closing the printing circuit momentarily at preset intervals, or to a "periodic cut-out" stage consisting of one type 42 tube, one AC relay R_5 and two relays R_3 and R_4 (STC, BPO ·3000 type). This periodic cut-out stage had to be provided because a 6 kW. pulse-transmitter was housed in the same building. Its aerial system had to be in close proximity (within less than 10 ft.) of the ionization-chambers and amplifier 1. Although the greatest care was taken to shield completely the chambers and amplifier 1, the ionosphere transmitter caused spurious pulses in the present unit. Since a time-switch of the synchronous clock-type put this transmitter "on the air" every 30 minutes for 170 seconds, the periodic cut-out is arranged in such a way that an AC relay closes when HT is applied to the transmitter. This causes the relay R_4 first to increase the bias on the input tube of amplifier 2 far beyond cut-off, while at the same time putting a negative pulse on the grid of the 42-tube. One hundred and seventy seconds later, when the pulse transmitter stops operations, R_5 opens, R_4 restores the normal working bias of the 6F5 tube, and a positive pulse is applied to the grid of the 42 tube, thereby momentarily closing relay R_3 and actuating the printing and resetting coils. The hourly number of counts is corrected for the counting time lost through the "periodic cut-out."

The entire plant as shown in Figs. 2, 3, and 4 has been mounted along the walls of a room 8½ ft. by 9 ft. Authorization for the construction of the equipment was given by the Assistant Director of Scientific Developments on 3rd July, 1944, and the first determinations were made on 15th September, 1944. The plant was used for the regular, periodic routine examinations of the entire staff of the luminizing department of the Dominion Physical Laboratory, and for the sporadic examination of four luminizers working for the R.N.Z.A.F. The examinations proved that the protective measures recommended for luminizing work in New Zealand were wholly successful in that all the workers examined at the end of their employment remained well within the tolerance limit for ingested and inhaled radium.

ACKNOWLEDGMENTS

Almost the entire costs of the equipment were covered by a War Cabinet grant of £120. Thanks are due to Mr. H. J. Yeabsley (who assisted with

the final adjustment of the plant and carried out a large number of radon determinations), to the British Empire Cancer Campaign Society for authorizing this work and its publication, and to Canterbury University College for providing the room for the equipment. It is a pleasure to acknowledge the whole-hearted and helpful co-operation of the Dominion Physical Laboratory (supplying at very short notice true to specifications and detailed drawings the bulk of the glassware, the ionization-chambers, and the furnace), and the Defence Development Section of the Department of Scientific and Industrial Research (supplying the oscilloscope and "scaler," and wiring amplifier 1 and its power supply).

REFERENCES

(1) "Safe Handling of Radioactive Luminous Compound" (1941): National Bureau of Standards Handbook H 27.
"Safe Health Practices relating to the Use and Handling of Radioactive Luminous Paints" (1942): Mass. Dept. of Labor and Industries, Publication No. 290.
(2) EVANS, R. D. (1943): *J. Ind. Hyg. & Toxicol.*, *25*, 253–69.
(3) JONES, J. C., AND DAY, M. J. (1945): *Brit. J. Radiology*, *18*, 126–31.
(4) EVANS, R. D. (1935): *Rev. Sci. Inst.*, *6*, 99–112.
(5) ——— (1935): *Phys. Rev.*, *48*, 177–86.
(6) POOLE, J. H. J. (1938): *Proc. Roy. Soc.*, *Dublin*, *21*, 595–608.
(7) READ, J., AND MOTTRAM, J. C. (1939): *Brit. J. Radiology*, *12*, 54–60.
(8) RAJEWSKI, B. (1941): *Strahlentherapie*, *69*, 438–502.
(9) URRY, W. D., AND PIGGOT, C. S. (1941): *Am. J. Sci.*, *239*, 633.
(10) BROWN, S. C.; ELLIOTT, L. G.; AND EVANS, R. D. (1942): *Rev. Sci. Inst.*, *13*, 147–51.
(11) CURTISS, L. F. (1942): *J. Ind. Hyg. & Toxicol.*, *24*, 131–41.
(12) RUSS, S. (1943): *Brit. J. Radiology*, *16*, 6–7.
(13) CURTISS, L. F., AND DAVIS, F. J. (1943): *U. S. Bur. Stand*, *J. Res.*, *31*, 181–95.
(14) EVANS, R. D. (1937): *Am. J. Roentg. & Ra. Ther.*, *37*, 368–78.
(15) EVANS, R. D., AND AUB. J. C. (1937): *Science*, *85*, 227–33.
(16) WADDELL, R. C. (1939): *Rev. Sci. Inst.*, *10*, 311–14.
(17) ZAGOR, H. I., AND VALENTE, F. A. (1945): *Phys. Rev.*, *67*, 133–42.

OXFORD CHALK

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INTRODUCTION

The Oxford chalk is a soft, fine-grained limestone, the best of which is almost white in colour.* The chalk has a variety of uses, and is at present being worked by the Austin Chalk Co., of Christchurch. The special value of the material lies in its softness, in which it is similar to the English chalk and very different from most of the New Zealand limestones, which are usually recalcified and much harder.

LOCATION

The Oxford chalk pits are about ten miles west of Oxford township, thirty miles north-west of Christchurch, and on the west side of White Creek, a tributary of the Eyre River. The chalk was first trucked direct to Christchurch, but is now trucked to Sheffield, ten miles to the south, and is then railed to Christchurch (Fig. 1).

* Library reference facilities were not available to the writer at Greymouth Previous geological work could not be reviewed.

Geology

An escarpment about 500 ft. in height extends for about a mile along the west side of White Creek from the junction of this stream with the south branch of Eyre River. The escarpment is controlled by a thick flow of basalt, which dips west under the gravels of the Canterbury Plains. The chalk outcrops along the face of this escarpment and is well exposed in three quarries. Only the largest quarry is at present worked. The figure (Fig. 2) shows the section exposed there.

The 3 ft. band of flint was sampled (K. 1221–3), but appears to be too impure to have economic importance. The upper part of the chalk (K. 1221–2) is impure and contains numerous glauconite-filled borings;

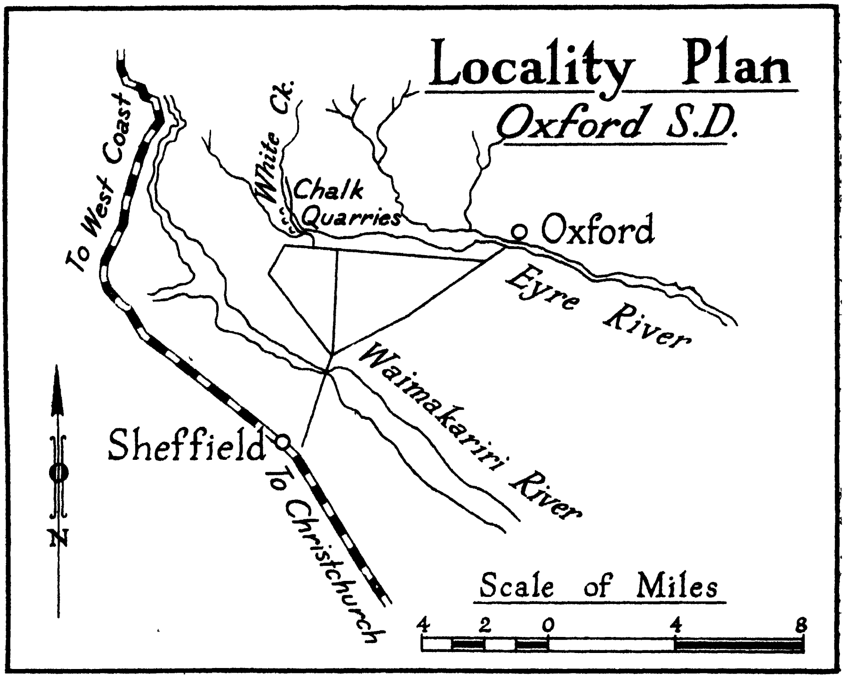


Fig. 1.

the lower part (K. 1221–3) is homogeneous and appears to be of even grade. No bedding planes are visible, and quarrying is partly controlled by strong regular vertical joints which strike along the face of the escarpment.

In the large quarry the overburden at the sides is less than 3 ft. thick, but the thickness increases towards the back of the quarry to over 30 ft. As the beds dip west under the basalt the quarry cannot be economically extended any farther back, and will have to be extended laterally either to the north or south. The extension of the chalk in both of these directions is proved by the old quarries, both of which show little overburden in the front. There is little doubt that several hundred thousand tons of easily worked chalk are available.

The bed immediately beneath the floor of the quarry is not exposed, but glauconitic quartz sandstone crops out about 20 ft. below the floor of the most northerly of the quarries, and it is probable that this forms

the floor of the pits and that it extends down to stream-level, where similar material is exposed at several places. The beds below this sandstone were not seen, and it is probable that greywacke underlies it at no great depth.

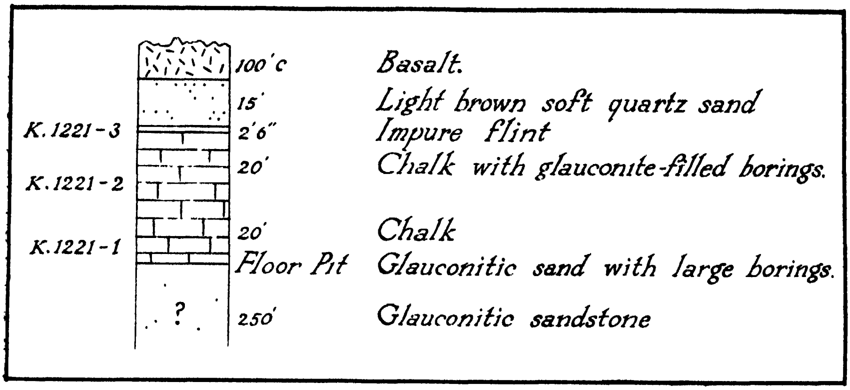


FIG. 2.

APPENDIX

LABORATORY INVESTIGATIONS

By L. R. L. DUNN, J. J. S. CORNES, and G. L. DEAN, Dominion Laboratory, Department of Scientific and Industrial Research

Oxford Chalk and Flint

K. 1221-1, G.S.: Lower homogeneous chalk.
-2, G.S.: Upper more impure.
-3, G.S.: Impure flint.

Analyses, per Cent.	K. 1221-1.	-2.	-3.
SiO_2 ..	15·93	22·52	76·52
Al_2O_3 ..	3·93	4·23	7·14
Fe_2O_3 ..	0·91	1·13	1·68
MgO ..	0·48	0·52	0·76
CaO ..	41·37	36·96	2·33
Na_2O ..	0·17	0·17	0·10
K_2O ..	0·60	0·70	0·70
TiO_2 ..	0·18	0·18	0·25
CO_2 ..	33·02	29·61	..
H_2O+ ..	1·83	1·96	4·97*
H_2O- ..	1·00	1·06	6·03
	99·42	99·04	100·48

* Includes some CO_2.

Oxford Flint

——	K. 1221-3.	Kaeo Flint.
	Per Cent.	Per Cent.
Soluble in caustic potash ..	88	35
Specific gravity	2·3	2·6

The material appears to be an impure opal or siliceous sinter and not a true flint. It burns reddish, and would therefore be valueless for ceramic purposes. Kaeo flint, on the other hand, burns quite white, and should be a valuable flint substitute.

FLINT, KAIKOURA

By H. W. WELLMAN, New Zealand Geological Survey, Department of Scientific and Industrial Research

[*Received for publication, 11th July, 1945*]

FLINT occurs in the railway cutting west of Mororimu Creek, a small stream entering the sea twenty miles north-east from Kaikoura. The band of Amuri Limestone that extends northward from the coast at Mororimu and crosses Clarence River about five miles above its mouth was examined at the coast and at several points where crossed by small north-flowing tributaries of the Clarence. The flint band is in the lower part of the limestone and is generally of poor grade. Inland the best material seen is exposed in a vertical face of about 10 ft., about 20 chains up Stewart Creek from the road along the south side of the Clarence, which Stewart Creek enters about three miles from the sea.

Fair-grade material occurs at the coast at Mororimu, where 2 ft. ellipsoidal masses of light-coloured flint are contained in a band of siliceous limestone. The total amount of flint of this kind that could be obtained at a reasonable cost is only a few tons. A 10 ft. outcrop of dark flint is exposed at the extreme south-west end of the beach (see figure).

A special look-out was kept for boulders of flint on the beach, for it was hoped that waterworn, naturally cleaned flint might be obtainable. Such material occurs only in very small quantities, for the high-grade rock is finely jointed and does not withstand wave action. Hornstone is probably a more correct name than flint for the siliceous rock. The most resistant material is the highly siliceous limestone, which contains far too much lime to be of value.

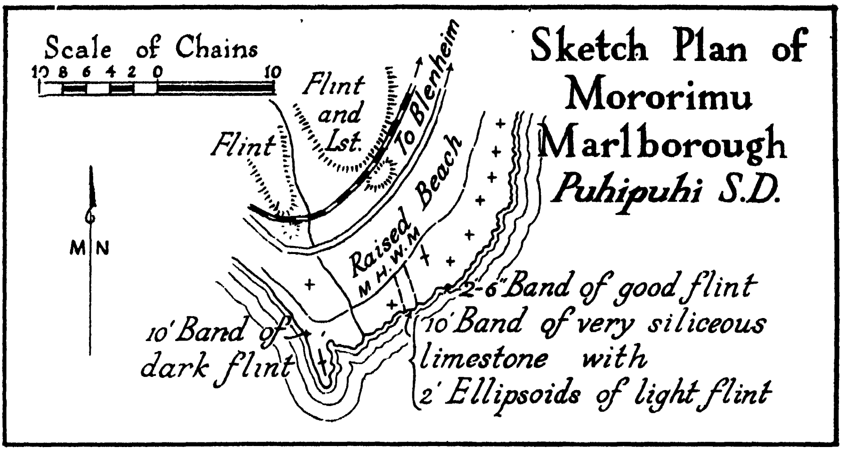
The northern end of Kaikoura Peninsula was also examined, but the flint seen there was of lower grade than that at Mororimu.

In 1935 Mr. L. R. L. Dunn, of the Dominion Laboratory, made an analysis of high-grade flint collected by Mr. H. E. Fyfe from the railway cutting 2 chains west of Mororimu Stream. Flint from South Australia used by potters in Australia was examined at the same time. The following are the results :—

	Mororimu.	South Australia.
Silica (SiO_2)	97·54	95·95
Alumina (Al_2O_3)	0·52	0·28
Ferric oxide (Fe_2O_3)	0·19	0·11
Lime (CaO)	Nil	0·91
Magnesia (MgO)	Nil	Nil
Water (combined and organic matter) ..	1·12	1·99
Water (lost at 100°)	0·28	0·37
	99·65	99·61

The Dominion Analyst (Mr. W. Donovan) noted (Lab. Memo., 8th October, 1935) that the fracture obtained when the Mororimu sample was crushed was distinctly splintery, and definite cleavage planes appeared to be present. The Australian flint was compact and showed the conchoidal fracture typical of flint. Upon strong ignition of the powdered samples the Mororimu material yielded a dull white product and the Australian a pure white.

He remarked that the New Zealand sample " contains a slightly higher content of iron oxide than the Australian, but in other respects compares favourably with the latter as regards chemical purity. The Australian flint contains a small amount of calcium carbonate, but the latter commonly occurs in association with flint and is not considered as an impurity.



" The fact that the Australian flint burns to a purer white than the New Zealand is due partly to the fact that it contains less iron compounds, but the effect of the calcium carbonate in neutralizing the colour produced by iron is probably the chief factor.

" Provided the deposit at Mororimu is sufficiently extensive, and equal in average composition to the sample submitted, it should be suitable as an ingredient for the manufacture of pottery.

" Owing to its splintery nature, it would not be suitable for use in ball mills for grinding operations."

HEAT-EVOLUTION CHARACTERISTICS OF NEW ZEALAND PORTLAND CEMENTS

By L. R. L. DUNN and F. T. SEELYE, Dominion Laboratory, Department of Scientific and Industrial Research

[Received for publication, 25th June, 1945]

Summary

In this paper results are recorded of a detailed analytical survey of the three brands of normal Portland cement manufactured in New Zealand. By applying to these results methods made possible by recent advances in the chemistry and technology of Portland cement clinker, the authors have been able to classify local cements with regard to heat-evolution characteristics. The high quality of all three cements has been confirmed.

INTRODUCTION

IN connection with the programme planned for further development of water-power in New Zealand, concrete is perhaps the most important constructional material that will be used. Engineers responsible for the

building of large dams are vitally interested in the quality of the cements available, and by means of regular strength tests keep a close check on all concrete being used. In the past in New Zealand the examination of cement by the chemist has usually been confined to a listing of oxide compositions in order to ensure that the chemical requirements of British Standard Specifications were being complied with.

Though such a method is useful, the chemical nature of a cement is not defined by stating its oxide composition. It is now recognized that the properties of cement are dependent upon the relative proportions of the true compounds present. During the last twenty years there has been an extraordinary amount of research by methods of high-temperature phase equilibria, especially by Rankin and Wright(1) at the Bureau of Standards, who worked out the system CaO-Al_2O_3-SiO_2. This was later extended by Lea and Parker(2) to include Fe_2O_3, thus covering the main cement compounds.

It is now generally agreed that cement clinker contains six phases :—

(1) Tricalcium silicate : $3CaO \cdot SiO_2$. Abbreviation, C_3S.

(2) Tricalcium aluminate : $3CaO \cdot Al_2O_3$. Abbreviation, C_3A.

(3) Tetracalcium aluminoferrite : $4CaO \cdot Al_2O_3 \cdot Fe_2O_3$. Abbreviation, C_4AF.

(4) Dicalcium silicate : $2CaO \cdot SiO_2$. Abbreviation, C_2S.

(5) Free lime : CaO.

(6) Periclase magnesia : MgO,

These compounds have all been artificially made, their optical properties are known, their heats of hydration have been measured, their x-ray diffraction patterns charted, and their reaction-products with water ascertained. A modern cement analysis is incomplete unless it includes a statement of the compounds present.

There are two main methods of determining the proportions of these compounds :—

(1) Accurate chemical analysis and calculation of compounds according to a procedure worked out by Bogue(3).

(2) Examination of polished and etched specimens of Portland-cement clinker according to methods described by Insley and others(4). The proportions of the constituents can be determined with an accuracy of the same order as is obtained by the chemical method, provided the difficult technique is mastered.

These modern concepts of cement chemistry have been applied to concrete practice in many directions, but more especially to the study of the heat-evolution which occurs in large masses of concrete such as dams.

Concrete, like most other materials, has a coefficient of thermal expansion, and as the concrete cools from the high temperature developed during setting and early hardening, shrinkage takes place and serious cracking may occur. There are many ways of avoiding such troubles—*e.g.*, use of elaborate cooling systems as in the construction of the Boulder Dam ; use of leaner mixtures ; use of Portland-pozzolanic cement ; or of cement less finely ground than usual.

In the United States, Sweden, and even in Australia, special grades of low-heat Portland cement are made. This is done by adjusting the composition of the mix to give as low as possible a proportion of C_3A in the cement, and a high proportion of C_2S.

Theoretically it would be possible to produce a cement consisting entirely of C_2S, but such a cement would be useless as it would lack early strength and, moreover, the absence of compounds of iron and aluminium would make it impossible to clinker the cement at a reasonably low temperature.

Low-heat cements have been found to be particularly suitable for large dams, as these are then freer from structural cracks than they would be if ordinary Portland cement had been used. Also, because of their low C_3S content, low-heat cements are less liable to chemical leaching by soft waters, an important advantage with hydraulic structures.

The actions (mainly hydration) that take place during the setting and hardening of the compounds present in cement are all accompanied by the evolution of considerable amounts of heat.

Lerch and Bogue(5) found from determinations of heats of solution of unhydrated and completely hydrated pure compounds that the heats of complete hydration for the cement compounds are as follows:—

—	Total.	First Forty-eight Hours.
	Calories/g.	
C_3A	207	150
C_3S	120	100
C_4AF	100	40
C_2S	62	..
CaO	279	..
MgO	203	..
SO_3	149*	..

* Due to formation of $3CaO \cdot Al_2O_3 \cdot 3CaSO_4 \cdot 31H_2O$.

Using Lerch and Bogue's results, it is possible to obtain an approximation to the heat-evolution properties of a cement from the analytical results. There are errors involved, however, as the calculation of compounds present is based on the assumption that the clinker is entirely crystalline, whereas with rapid cooling a proportion of glass may be present.

EXPERIMENTAL

At the suggestion of the Chief Engineer, Public Works Department, samples of cement and clinker from current production were obtained from the manufacturers in well-sealed containers as follows:—

K. 2085–1 .. Cement "clinker," manufacturer "A."
–2 .. Cement "clinker," manufacturer "B."
–3 .. Cement "clinker," manufacturer "C."

K. 2467–1 .. Normal cement, manufacturer "A," 28th August, 1944.
–2 .. Normal cement, manufacturer "B." 28th July, 1944.
–3 .. Normal cement, manufacturer "C," 11th July, 1944.

NOTE.—In the case of K. 2467–2, cement from "B," the manufacturer advised that this sample did not correspond with the clinker sample previously forwarded (K. 2085–2), as the former was a later burning. Both, however, were of normal quality.

The clinker and cement samples from "C" were corresponding materials as regards burn.

Cement "A" was received at a later date than the clinker, and may have been a later burn, but no information from the manufacturer on the point was received.

Analyses

Chemical analyses were carried out on all samples and "compound" compositions worked out, with the following results:—

Clinkers.	"A": K. 2085–1.	"B": K. 2085–2.	"C": K. 2085–3.
Silica (SiO_2), per cent.	21·83	23·80	23·64
Alumina (Al_2O_3), per cent.	5·00	5·18	4·06
Iron oxide (Fe_2O_3), per cent.	3·75	3·12	3·57
Total lime (CaO), per cent.	65·49	65·61	65·33
Free lime (CaO), per cent.	(2·00)	(0·22)	(0·26)
Magnesia (MgO), per cent.	1·83	1·18	1·08
Sulphur trioxide (SO_3), per cent.	0·62	0·07	1·32
Loss on ignition, per cent.	0·11	0·04	0·14
Soda (Na_2O), per cent.	0·65	0·26	0·29
Potash (K_2O), per cent.	0·45	0·35	0·37
Titanium dioxide (TiO_2), per cent.	0·32	0·32	0·24
Phosphoric anhydride (P_2O_5), per cent.	0·13	0·15	0·19
Manganous oxide (MnO), per cent.	0·06	0·02	0·11
	100·24	100·10	100·34

COMPOUND COMPOSITIONS OF CLINKERS

—	"A."	"B."	"C."
C_3S	51·69	45·62	48·84
C_3A	6·89	8·43	4·72
C_4AF	11·40	9·48	10·85
C_2S	23·66	33·90	31·01
CaO (free)	2·00	0·22	0·26
MgO	1·83	1·18	1·08
$CaSO_4$	1·05	0·12	2·24

ANALYSES OF CEMENTS

—	"A": K. 2467–1.	"B": K. 2467–2.	"C": K. 2467–3.
SiO_2, per cent.	20·86	23·44	23·24
Al_2O_3, per cent.	5·08	5·00	4·22
Fe_2O_3, per cent.	3·08	2·56	3·15
CaO (total), per cent.	63·96	63·84	64·66
CaO (free), per cent.	(2·64)	(1·00)	(0·38)
MgO, per cent.	1·66	1·18	1·02
SO_3, per cent.	1·85	1·57	1·86
Loss on ignition, per cent.	1·72	1·19	0·70
Soda, per cent.	0·67	0·33	0·33
Potash, per cent.	0·48	0·47	0·36
TiO_2, per cent.	0·31	0·29	0·24
P_2O_5, per cent.	0·10	0·13	0·13
MnO, per cent.	0·045	0·015	0·10
	99·82	100·02	100·01
"Insoluble residue" (included in main analyses), per cent.	0·35	0·15	0·18

The requirements for chemical composition of Portland cement as set out in *B.S.S. No. 12*, 1940, are given below, as well as results for the three local cements. Though not required for heat-evolution calculations, the results are given so that they may be put on record.

—	"A" Cement.	"B" Cement.	"C" Cement.	Requirements of *B.S.S. No. 12*, 1940.
Ratio $\frac{CaO}{2{\cdot}8\,SiO_2 + 1{\cdot}2\,Al_2O_3 + 0{\cdot}65\,Fe_2O_3}$	0·94	0·86	0·88	Not < 0·67 nor > 1·0.
Ratio $\frac{Fe_2O_3}{Al_2O_3}$	0·60	0·51	0·75	Not more than 1·5.
Insoluble residue, per cent.	0·35	0·15	0·18	Not more than 1·0.
Magnesia (MgO), per cent.	1·66	1·18	1·02	Not more than 4·0.
Sulphuric anhydride (SO_3), per cent. ..	1·85	1·57	1·86	Not more than 2·75.
Loss on ignition, per cent.	1·72	1·19	0·70	Not more than 3·0.

The three cements therefore easily comply. *B.S.S. No. 12*, 1940, sets no limits for alkali content and free lime and does not consider heat-evolution.

COMPOUND COMPOSITION OF CEMENTS

Phase.	"A"	"B."*	"C"
C_3S	47·09	35·78	46·72
C_3A	8·24	8·90	5·83
C_4AF	9·36	7·78	9·58
C_2S	24·35	40·28	31·46
CaO (free)	2·64	1·00	0·38
MgO	1·66	1·18	1·02
$CaSO_4$	3·15	2·67	3·16

* The difference in compound composition of the clinker and of the cement in the case of "B" is due to the fact that the materials were from different burnings, as explained previously.

CALCULATION OF HEAT-EVOLUTION CHARACTERISTICS OF CEMENTS

Heat-evolutions were calculated from compound compositions according to the procedure given by Lea and Desch in "The Chemistry of Cement and Concrete," p. 183, Table XXV. Allowances were made for heats of hydration of CaO (free) and MgO (279 and 203 calories per gram respectively), and for heat-evolution due to interaction between $CaSO_4$ and hydrated C_3A, as recommended by Lea and Desch. Calculation of heat-evolution in this way is, as noted above, subject to certain inaccuracies and assumptions, the main error being due to the fact that no correction can be made for "glass." However, work at the Bureau of Standards(4) has shown that the method compares favourably with the microscopical method and gives results in reasonable agreement with direct measurement of heat-evolution.

The results for heat-evolution obtained in this way are set out in the following table, together with average figures for various classes of Portland cement taken from a paper by Lea(6) on "Modern Developments in

Cements," published in the *Journal of the Institution of Civil Engineers*, February, 1943, No. 4, p. 238:—

—	Heat-evolution.		Calories per gram.*	
	Three Days.	Seven Days.	Twenty-eight Days.	Complete Hydration.
K. 2467-1: "A"	81	89	99	112
-2: "B"	68	74	88	102
-3: "C"	70	78	89	103
Rapid-hardening Portland cement	90	100	110	..
Normal Portland cement	75	85	90	..
Modified Portland cement	65	75	80	..
Low-heat Portland cement	45	55	65	..
United States specifications for low-heat cement	..	65	75	..

* 1 calorie per gram = 1·8 B.Th.U. per pound.

PETROGRAPHICAL EXAMINATIONS OF CLINKERS

An attempt was made to confirm the results obtained by the chemical method by means of petrological examinations of thin sections of the clinkers. Unfortunately, a suitable impregnating resin was not available and preparation of the sections was extremely difficult. The examination of thin sections was therefore abandoned in favour of the examination of polished sections.

The main recognizable constituents were found to be C_3S and C_2S, with C_4AF as a minor constituent. In addition to the above minerals, the clinkers contained a small amount of apparently isotropic material which presumably consisted of tricalcium aluminate or glass or both together. It was found impossible to distinguish between C_3A and glass under the microscope. Quantitative estimations of the cement compounds by optical methods were therefore unsuccessful.

CONCLUSIONS

The results indicate that none of the New Zealand cements, as was to be expected, comes into the "low-heat" or "modified Portland cement" classes. "A" cement is appreciably higher in heat-evolution than the other two brands, but this may be partly explained by experimental errors in the analyses and inaccuracies in calculations due to "glass."

Heat-evolution, particularly in the early stages, would be affected to some extent by fineness of grinding, but data on the relative finenesses of the respective cements are not available.

Low-heat Portland cements generally contain not more than 25 per cent. to 30 per cent. of C_3S and in the neighbourhood of 50 per cent. C_2S, the strength-producing compound which contributes to a steady gain of strength over a long period of time. C_3A in such cements is usually from 5 per cent. to 6 per cent., with a top limit in some specifications of 7 per cent. It is therefore clear, from the compound compositions previously tabled, that none of the New Zealand cements comes into the low-heat class.

The presence of free lime in cement "A" and clinker suggests that the temperature of burning or of the exit gases may not be as high as that used in the other works. This may be a possible explanation of the rather higher alkali content of cement "A," since at very high temperatures alkalies may be lost to a considerable extent by volatilization. The significance of alkalies in Portland cement has recently been reviewed by Sutton(7).

The range of alkali contents of the three New Zealand brands of cement has been determined from numerous samples by Seelye and by Cornes(8), and the position is still being closely watched.

As far as the authors are aware, no cases of deterioration of concrete due to interaction of cement of high alkali content with aggregate have been reported in New Zealand, and unless evidence to the contrary is brought forward it must be assumed that the concrete aggregates commonly used here are safe.

In conclusion, it may be stated that the results of these investigations have confirmed the very high standard of quality of all three brands of locally made cement. It now remains for the engineers to decide whether it will be necessary, for mass concrete work, to manufacture special low-heat cements in New Zealand, or whether attention should be given to the development of special low-heat pozzolanic cements such as have been used for dams in other countries.

If at any future time the production of such special cements is decided upon by the manufacturers, further consideration of the question of direct measurement of heat-evolution will be necessary, and a specification covering such cements will have to be drawn up.

ACKNOWLEDGMENTS

The authors wish to express thanks to the managers of all three cement companies for assistance in supplying samples and for permission to publish these results; to Dr. C. O. Hutton for supervision of petrographical work; to Mr. P. J. Clark for free-lime determinations; and to Mr. R. L. Andrew, Director, Dominion Laboratory, for consent to publish this paper.

REFERENCES

(1) RANKIN, G. A., and WRIGHT, F. E. (1915): *Am. J. Sci., 39* (4), 1.
(2) LEA, F. M., and PARKER, T. W. (1935): *Bld. Res. Techn. Paper, No. 16.*
(3) BOGUE, R. H. (1929): *Ind. Eng. Chem. Anal. Ed., 1*, 192.
(4) INSLEY, H., and others (1938): *Bur. Standards J. Res., 21*, 355.
(5) LERCH and BOGUE (1934): *Bur. Standards J. Res., 12*, 645.
(6) LEA, F. M. (1943): *J. Inst. Civ. Eng. (No. 4)*, 224.
(7) HUTTON, C. O. (1945): *N.Z. J. Sci. & Tech., 26* (Sec. B), 164.
(8) CORNES, J. J. S. (1945): *N.Z. J. Sci. & Tech., 26* (Sec. B), 239.

NOTE ON A TABLE OF DISTANCES FROM SOUTH PACIFIC SEISMOLOGICAL OBSERVATORIES

By W. M. JONES, Dominion Observatory, Department of Scientific and Industrial Research

[Received for publication, 1st August, 1945]

Summary

A table has been compiled, mainly for seismological purposes, giving, in degrees and minutes, the "geographical" distances from five South Pacific observatories to points, at intervals of one degree in latitude and longitude, in the South Pacific region, from 0° to 35° south latitude, and from 160° east to 170° west longitude. A sample sheet only is printed here, as basis for a brief discussion of the Table.

INTRODUCTION

FOR some recent seismological studies the writer had occasion to compute the "geographical" distances, in degrees and minutes, from Wellington,

Brisbane, and Suva Observatories to each of the 1,116 intersections of degree-lines of latitude and longitude in the region comprised between 0° and 35° south latitude and between 160° east and 170° west longitude. The corresponding distances from Riverview and Apia Observatories have since been added, so that a table is now available which may be of use to seismologists working on South Pacific problems, and perhaps also for purposes of air navigation or of radio-transmission. The table is somewhat lengthy for printing in this *Journal*, and only a sample sheet is given below, for purposes of discussion. A few typed copies are available, and the writer would be glad to forward one to any observatory or private worker who would have use for it. It is hoped also, as occasion offers, to extend the region covered.

DESCRIPTION AND DISCUSSION OF THE TABLE

The heading gives the geographical latitude, the longitude, and the geographical direction-cosines of the five observatories, with identification letters for the columns in the table. The distances, in degrees and minutes, are shown separately for each meridian, the sample shown being for 160° east, and can be converted into miles or kilometres, if required, at the approximate rate of 69 miles or 111 kilometres per degree (with limitations arising from the earth's ellipticity). The dot after figures in the minutes column indicates a half-minute, and has been inserted when entry into the five-figure haversine table used (that in Bowditch, American Practical Navigator) indicated the half-minute as a closer approximation than the preceding or following minute. It does not mean, however, that a half-minute accuracy is everywhere attained, as a glance at the first differences will show; but only that, in general, a slightly greater accuracy will be obtained by its inclusion.

The process of computation employed the direction-cosines, to four figures, previously obtained by the writer from five-figure trigonometrical tables(1), and the formula

$$\text{haversine } \Delta = \frac{1}{4}\left\{(a - \mathrm{A})^2 + (b - \mathrm{B})^2 + (c - \mathrm{C})^2\right\}$$

where a, b, c are the direction-cosines of an observatory, and A, B, C those of the point considered. The squares were written down to the fifth figure, the sum divided by 4, and the angle looked up in the Bowditch five-figure haversine-table. Owing, however, to the slow variation of the haversine for small angles, this procedure does not give an accuracy of a minute for distances less than about 5°, and over this range the following formula was used—

$$\Delta^2 = (\mathrm{A}\cdot\Delta\lambda)^2 + (\Delta\phi)^2$$

where $\Delta\lambda$ and $\Delta\phi$ are the differences in longitude and latitude between observatory and point considered, and A the ratio of the length of a degree of longitude to that of one of latitude, an average value being taken over the range of 5°.

Thus, while it would not be safe to expect that the nearest half-minute is everywhere accurate, it is hoped that where ellipticity corrections are not being taken into account the accuracy attained will be sufficient for most purposes of present-day South Pacific seismology. For example, an error of a minute, or about a mile, is comparable with about a fifth-second in the measurement of the time of arrival of a P-wave, or a third-second for an S-wave, and our South Pacific observatories are not yet normally concerned with time-intervals of this order in the recording of earthquakes at the distances concerned.

TABLE

Geographical distances, in degrees and minutes, from—

A. Wellington, 41° 17′ S., 174° 46′ E.: $a = -\cdot7483$, $b = +\cdot0685$; $c = -\cdot6598$
B. Brisbane, 27° 29′ S., 153° 02′ E.: $a = -\cdot7907$: $b = +\cdot4023$; $c = -\cdot4614$
C. Suva, 18° 09′ S., 178° 27·5′ E.: $a = -\cdot9499$; $b = +\cdot0256$; $c = -\cdot3115$
D. Riverview, 33° 50′ S., 151° 10′ E.: $a = -\cdot7277$; $b = +\cdot4006$; $c = -\cdot5568$
E. Apia, 13° 48′ S., 171° 47′ W.: $a = -\cdot9612$; $b = -\cdot1388$; $c = -\cdot2385$

Longitude, 160° E.

S. Lat.	A.		B.		C.		D.		E.	
°	°	′	°	′	°	′	°	′	°	′
0	43	24	28	17	25	39	34	50	31	09·
1	42	26·	27	18·	24	57	33	52	30	43
2	41	29	26	20	24	15·	32	53	30	17
3	40	31·	25	22	23	35	31	55	29	53
4	39	34	24	24	22	56·	30	57	29	30·
5	38	37	23	26	22	19	29	58·	29	09·
6	37	40	22	28·	21	43	29	01	28	50
7	36	43	21	31	21	09	28	03	28	33
8	35	46	20	33·	20	37	27	05	28	17
9	34	50	19	37	20	07	26	08	28	03
10	33	53	18	40·	19	39	25	10·	27	51
11	32	57	17	44	19	13	24	13·	27	41
12	32	01	16	48	18	50	23	16·	27	33
13	31	05	15	53	18	30	22	20	27	26·
14	30	09·	14	58	18	12	21	23·	27	22·
15	29	14	14	03·	17	58	20	27·	27	20·
16	28	19	13	10	17	46	19	32	27	20
17	27	24	12	17·	17	37·	18	36	27	22
18	26	30	11	26·	17	32·	17	42	27	26
19	25	36	10	37	17	30·	16	47·	27	32
20	24	42·	9	49·	17	32	15	54	27	40
21	23	49·	9	04	17	36	15	01·	27	49·
22	22	57	8	22	17	44·	14	10	28	01
23	22	05	7	43·	17	56	13	19	28	15
24	21	14	7	10	18	10	12	29·	28	30·
25	20	23	6	43·	18	27·	11	42·	28	47·
26	19	33	6	23·	18	47·	10	56·	29	06·
27	18	44·	6	13	19	10	10	13·	29	27
28	17	57	6	11	19	35·	9	33	29	50
29	17	11	6	19	20	03	8	57	30	13
30	16	26	6	36·	20	33	8	25	30	39
31	15	43	7	01·	21	05	7	58	31	05·
32	15	01	7	33	21	39	7	38	31	33·
33	14	22	8	10	22	14	7	25·	32	03
34	13	45	8	51	22	51·	7	20	32	34
35	13	11	9	35	23	30·	7	22	33	06

INTERPOLATION

For points not on the intersections of degree-lines it will in general be necessary to interpolate simultaneously for increments of both latitude and longitude. If ϕ, ϕ_0 are the latitudes of the point and the observatory, λ, λ_0, the longitudes, and δ the angular distance, then differentiation of the formula

$$\cos \delta = \sin \phi \sin \phi_0 + \cos \phi \cos \phi_0 \cos (\lambda - \lambda_0)$$

gives

$$-\sin \delta \, \Delta\delta = \left\{\cos \phi \sin \phi_0 - \sin \phi \cos \phi_0 \cos (\lambda - \lambda_0)\right\} \Delta\phi$$
$$- \cos \phi \cos \phi_0 \sin (\lambda - \lambda_0) \, \Delta\lambda$$

thus expressing an increment of distance $\Delta\delta$ in terms of given increments

$\Delta\phi$ and $\Delta\lambda$; but the factors to be applied to $\Delta\phi$ and $\Delta\lambda$, varying as they do for each original latitude and longitude, are evidently too complicated for easy interpolation. Richter(2) gives relations obtained by expansions in series. However, except for the shortest distances, it should suffice for our purposes to neglect second order terms, and to make a linear interpolation as follows :—

If Δ_1, Δ_2 are distances given in the table for two successive degrees of latitude on the same meridian, and Δ_3, Δ_4 those for the same latitudes on the next meridian, and if the point P has latitude x minutes greater than the point for which the distance is Δ_1, and longitude y minutes greater, then the distance at P will be approximately

$$\Delta_1 + (x/60)(\Delta_2 - \Delta_1) + (y/60)(\Delta_3 - \Delta_1)$$

The difference between this and the distance derived in a similar manner from Δ_2, Δ_3, and Δ_4 would show whether the error in interpolation is worth further consideration for the purposes involved.

REFERENCES

(1) JONES, W. M. (1944): Table of Direction-cosines to Four Figures, &c. *N.Z. J. Sci. & Tech.*, *26* (Sec. B), 155.
(2) RICHTER, C. F. (1943): Calculation of Small Distances. *Bull. Seism. Soc. Am. 33, No. 4*, 237.

TORNADOES IN NEW ZEALAND

By C. J. SEELYE, Meteorological Office, Wellington

[*Received for publication, 27th July, 1945*]

Summary

In recent years an average of 9 tornado storms a year has been recorded in New Zealand, but their frequency being certainly higher than reports reveal, is possibly 25 or more a year. A typical, well-developed tornado in this country would be one with a diameter of 20 yards and a track of 2 miles. They may occur any time of the day, but are appreciably more numerous in the afternoon, in which period there is a slight predominance of the stronger storms. Their average strength is greatest during the period May to October. Western districts of the Dominion, but especially Westland and the environs of Mount Egmont, including New Plymouth, are the most susceptible to tornadoes.

The majority are associated with cold fronts, particularly with those occurring in south-westerly situations—*i.e.*, those with an anti-cyclone located over south-eastern Australia.

About 30 per cent. of the reports refer to thunder or hail storms with the tornado, and another 10 per cent. to rain alone.

Brief descriptions, based on press reports, are given for the 8 most severe tornadoes of recent years.

GENERAL

ALTHOUGH tornadoes are relatively rare in this country there are far more of these vigorous storms than is generally realized and they are sufficiently numerous to merit attention. For this discussion 162 reports of tornadoes, including a few waterspouts viewed from the coast, have been considered.

A tornado is a violent whirl of small area around which winds spiral clockwise (in the southern hemisphere) and in which there are strong ascending currents near the core. Usually a funnel-shaped cloud hangs

from the cumulonimbus clouds and extends towards the earth. When a funnel-shaped cloud occurs at sea it is usually described as a waterspout. Dust-whirls or dust-devils are of a similar but much milder character, forming, however, from the ground following intense surface heating, whereas the tornado develops downward from the clouds above.

Tornadoes attain their greatest violence over the plains of the United States, and are not uncommon in parts of Australia. In Europe they are a rarity and much less violent. The American storms range in diameter from 40 ft. to over 1 mile, but are most commonly 500 to 1,000 ft., with a track length of 20 to 40 miles, although some have travelled 300 miles. Where dimensions have been given for New Zealand storms they have been mostly about 20 yards for the diameter, the smallest mentioned being 12 yards, and the largest, an isolated case, 200 yards. Often the track appears to be only about 2 miles long, but may exceed 10 miles.

It will be realized, therefore, that many storms of typical size, 20 yards through and travelling a few miles at a speed of, say, 30 miles an hour, may pass unnoticed in many of the mountainous regions and less-settled districts of this country. Moreover, those occurring during the hours of darkness if not very violent will often attract little attention and will escape any mention in the press. The majority of the records available are in fact derived from contemporary newspaper accounts, but a few have been noted in various meteorological returns supplied to this Office. The descriptions in a number of cases are meagre, but others contain much useful and vivid detail. All the 162 reports of tornadoes and waterspouts considered here relate to storms since 1919. In addition, there were several minor references too vague to be used here. Files of press reports prior to 1928 may not be complete, but since then the average number of such storms reported a year is 9, and whereas only 3 were recorded in 1940, there were reports of 23 during 1935. Therefore it is considered that the late Dr. E. Kidson did not overstate the case when, in an article appearing in the *Taranaki Daily News* of 11th June, 1934, he estimated 24 as the annual average of tornadoes both large and small.

GEOGRAPHICAL DISTRIBUTION

Auckland and Taranaki Provinces and the West Coast of the South Island are the areas most affected, as is seen by reference to Fig. 1, which shows the geographical distribution of the 162 occurrences. The deficiencies of this figure due to lack of reports must again be emphasized. It is felt that there will be many omissions for the West Coast of the South Island, especially south of Hokitika, and others between Mokau and Raglan in the North Island. Around Mount Egmont and at New Plymouth reported storms reach their greatest density, but this is also a region where observations are likely to be reasonably complete.

There is some similarity between the distribution of tornadoes and those of thunderstorms (Kidson and Thomson), both phenomena attaining their greatest frequency in western districts. There is a patch of tornadoes in Canterbury where thunderstorms are relatively rare, but the former includes several mild occurrences, possibly only dust-whirls. Both thunderstorms and tornadoes require a temperature lapse rate greater than the saturated adiabatic and a suitable supply of atmospheric moisture from below. Indeed, tornadoes are often accompanied by electrical disturbances. About 30 per cent. of the reports contain specific mention of thunder, lightning, or hail, and a further 10 per cent. of rain alone.

ANNUAL AND DIURNAL VARIATIONS

For the present survey an arbitrary scale ranging 0 to 5 units was adopted to indicate the intensity of a tornado, as, for example :—

0 Funnel cloud and no surface phenomenon; or very slight disturbance.

3 Outbuildings, verandas, and roofs carried away.

5 Well-constructed buildings demolished.

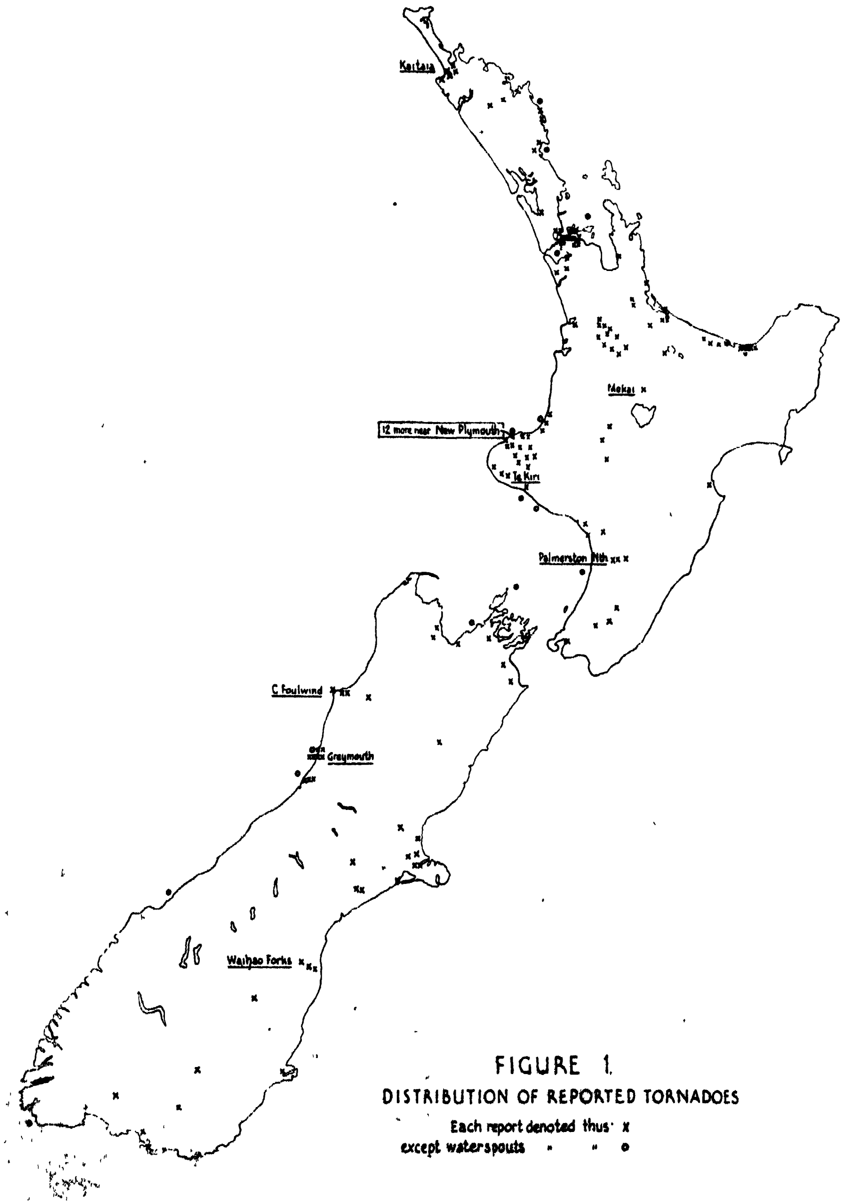


FIGURE 1.
DISTRIBUTION OF REPORTED TORNADOES

Each report denoted thus x
except waterspouts " " o

Table I shows the annual variation by the percentage of the total number of tornadoes which have occurred in each month and also their average intensity on the preceding scale.

TABLE I

(a) Annual Variations of Tornadoes in New Zealand: Percentage of Total.
(b) Average Intensity of Tornadoes in New Zealand (Arbitrary Scale).

	Jan.	Feb.	Mar.	Apr.	May.	Jun.	July.	Aug.	Sept.	Oct.	Nov.	Dec.	Year.
(a) ..	7	10	10	9	10	10	4	12	8	9	4	7	100
(b) ..	1·8	1·4	1·3	1·8	2·4	1·9	2·2	2·5	1·9	1·9	1·5	1·8	1·9

The distribution is, on the whole, fairly even, although July and November are conspicuous for their small frequency. The average intensity is greatest over the six-monthly period May to October.

The exact times of occurrence were recorded for 109 tornadoes, and for another 37 there were less precise indications of the time of day. After estimating a distribution for the latter, Table II was obtained. The diurnal variation expressed in graphical form is shown in Fig. 2.

TABLE II.—DIURNAL VARIATION OF TORNADOES: PERCENTAGE FREQUENCY

Hours.	0–2.	2–4.	4–6.	6–8.	8–10.	10–12.	12–14.	14–16.	16–18.	18–20.	20–22.	22–24.
Percentage frequency	4	3	4	6	8	8	12	18	15	13	6	3

There is a very definite maximum occurring in the mid-afternoon. As to some extent this may be due to many of slight intensity, a further analysis (Table III) was made to determine the distribution of storms of intensity 3 or more and also the variation of intensity.

TABLE III.—DAILY VARIATION OF TORNADOES WITH RESPECT TO FREQUENCY AND INTENSITY

Period.	Percentage Number.		Average. Intensity.
	Of Total.	Of all of at Least Intensity 3.	
Early morning	11	15	2·2
Forenoon	22	26	2·1
Afternoon	45	33	1·7
Evening	22	26	1·9

The results in the second column do not indicate quite such a marked predominance for the afternoon period. Undoubtedly the high average intensity for the early morning is a reflection of the weakness of the observational material for a period when only the more severe visitations leaving signs of destruction will be recorded. These data suffice to show the expected influence of convection during the afternoon as a contributory but by no means a necessary factor in the development of tornadoes here.

ASSOCIATED WEATHER TYPES

For the 61 examples occurring since 1937 the associated meteorological situations shown on the current synoptic charts have been examined. There were 46 per cent., and probably another 21 per cent. of these connected with the passage of a front, but the remaining 33 per cent. appear to have been of non-frontal origin. Table IV contains an approximate classification of these cases.

TABLE IV.—NUMBER OF TORNADOES WITH WEATHER TYPES

Weather Type.	Frontal.	Probably Frontal	Non-frontal.	Total.
South-westerly	4	7	7	18
Westerly	2	2	0	4
Trough	2	2	1	5
Depressions	8	2	5	15
Convective	0	0	5	5
Others	12	0	2	14
Total	28	13	20	61

A south-westerly type is one with an anticyclone over south-eastern Australia and a broad south-westerly wind flow over the Tasman Sea and New Zealand, often with active depressions to the south-east. In the westerly type an anticyclone orientated in an E.–W. direction is located to the north, while disturbances pass to the south. Under "trough" have been included situations where most of the Tasman Sea and New Zealand was in a wide trough of low pressure. Tropical cyclones have been included with depressions, and 8 of the 15 were centred to the south of the tornado. Quiet situations where surface temperatures and humidities were rather high have been classed here as convective.

South-westerly situations are thus very notable as favourable for tornado development. In such situations the polar air in the south-westerly current may be extremely unstable. With a secondary cold front tornadoes may develop on both sides of the Southern Alps. For example, on the 28th February, 1943, after the main cold front had passed, a waterspout was visible from Cobden, Greymouth, for half an hour following 9.23 a.m., and at about 11 a.m., associated with the same secondary cold front there was a very active tornado at Kaiapoi on the east coast.

DESCRIPTIONS OF TORNADO DAMAGE

The damage caused by tornado is a result of—

(*a*) The violence of the wind :

(*b*) The sudden lowering of pressure as the centre of the vortex passes, which tends to make closed buildings explode outwards :

(*c*) Further wind damage following entry through lifted roofs, &c. :

(*d*) Damage through flying debris elevated by the strong ascending currents.

In the following paragraphs brief accounts will be given of the 8 most severe tornadoes included in the records considered, free use being made of press reports. Descriptions of the damage done have been limited to a few

selected items. The place names for these tornadoes have been included in Fig. 1 :—

1. *Cape Foulwind* (11th August, 1927, about 2.45 a.m.).—A tornado swept through Cape Foulwind in a north-to-south direction, carrying everything before it. Large, substantial buildings were simply demolished, timber and iron being scattered in all directions. Portions of the buildings destroyed were found as far distant as half a mile from the place where they formerly stood. The Cape Foulwind School, Costello's Hall, and the old hotel were practically wiped out of existence, all that remained being a tangled mass of timber and iron.

2. *Allanholme, Waihao Forks, Waimate* (7th January, 1929, about 3 p.m.).—A homestead, with six occupants at the time, was lifted some

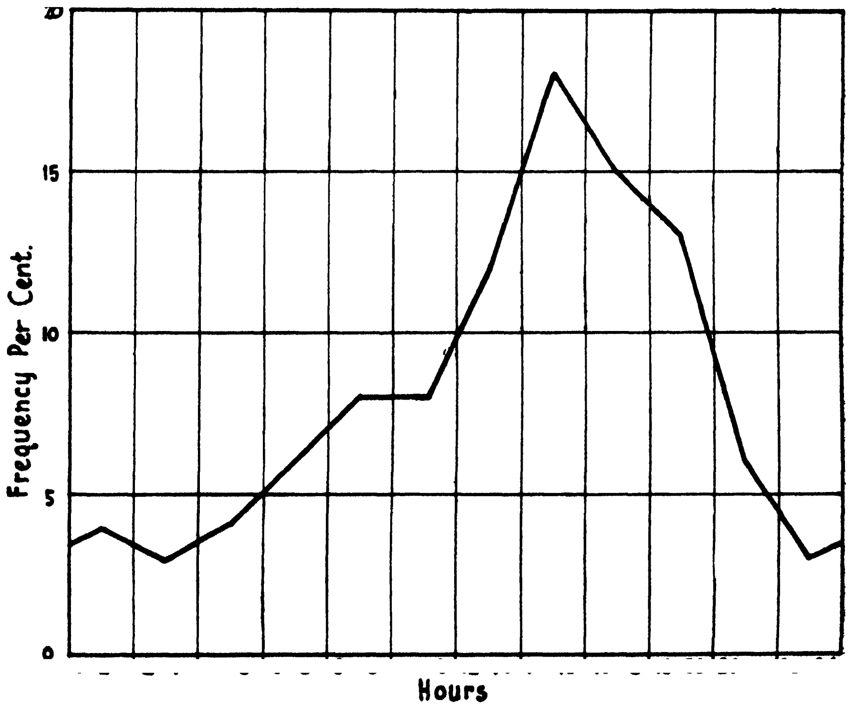


FIGURE 2. DIURNAL VARIATION OF FREQUENCY OF TORNADOES.

2 ft. off its bearings and turned round slightly. The kitchen chimney and the washhouse chimney were levelled, and the iron roof torn off the washhouse and off parts of the house. Much greater damage was done to trees and implements in the vicinity. At the Allanholme Coal-mine, 8 chains distant, a small house was lifted and half of it carried over 2 chains away. All the mine staging was pulled down. Other farms 14 and 30 chains away were almost untouched.

3. *Palmerston North* (24th June, 1929, about 3.30 p.m.).—Whirling along with amazing rapidity and terrible force, a tornado blasted a line of destruction several chains wide through the suburban area of Palmerston

North, partially unroofing houses, bringing down chimneys, and shattering windows. The tornado came from the direction of Kairanga, for a plantation in lower Aorangi was levelled and jagged ice fell. It cut a diagonal track through the residential area (as indicated approximately in Fig. 3) traceable for a distance of about 5 miles. A funnel cloud was observed to hover over the affected area.

4. *New Plymouth* (17th May, 1934, at 5 p.m.).—This tornado emerged from behind the Sugar Loaves at Moturoa and passed the waterfront in the region of the Ngamotu Palladium. " It was like a huge ball of fire rolling over the water." Its general easterly course is shown in Fig. 4. As a consequence at least eight houses were partly or wholly unroofed or damaged in other ways, some chimneys were demolished, many masts and poles broken, and trees blown down. It was accompanied by drenching rain as if from a cloud burst, by a diabolical roar and by an awesome electrical display.

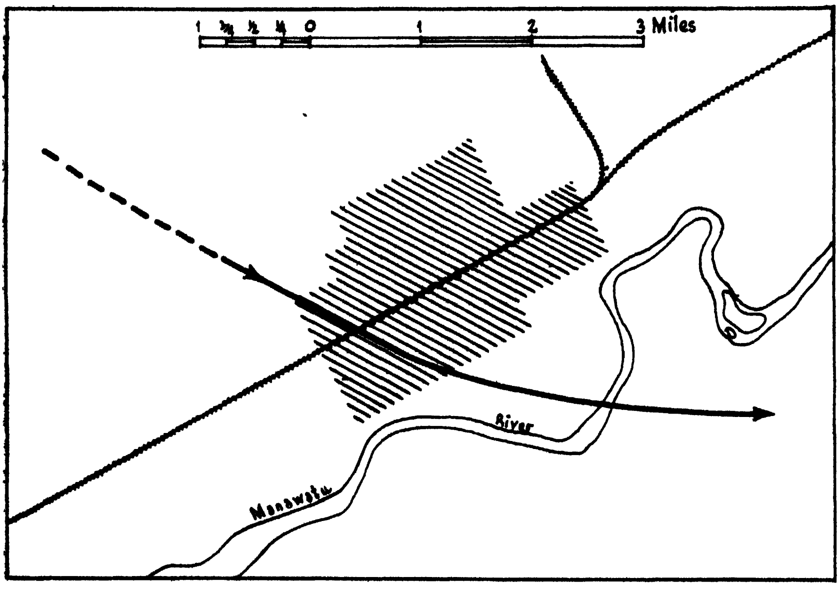


FIGURE 3. TORNADO TRACK: PALMERSTON NORTH, 24TH JUNE 1929.

5. *Greymouth* (29th March, 1936, at 8.50 a.m.).—Sweeping in from the sea about 300 yards south of the south breakwater, a tornado caused heavy damage to property over a belt across the town, leaving in its wake scores of broken windows, flattened fences, partially unroofed houses, and even completely wrecked buildings. It was the worst phenomenon of the kind Greymouth has experienced. After strong south-westerly winds had prevailed overnight there was a temporary change to the north-west, during which there was a thunderstorm and a heavy shower of rain and hail. Shortly after the tornado cut a swath from the west across the central portion of the town, swirling roofing, iron, and other debris high in the air ; in fact, it was through flying timber and iron that the greatest damage was caused. All told, some fifty buildings were affected, apart from fences and poles. The only buildings beyond repair were the Surf Club Pavilion and the sash and door factory. At one stage the width was given as 150 ft.

at a later stage 40 ft. Rain accompanied and followed this visitation. Figure 5 shows the track.

6. *Te Kiri* (29th August, 1936, afternoon).—After a brief calm following a heavy hailstorm, this tornado came down from Mount Egmont in a wild burst of fury. In the first farm affected a cow-shed was lifted 200 ft. into the air and carried some distance away. In neighbouring farms two cow-sheds and three haystacks fastened down with iron were wrecked. Then a four-roomed house was demolished. It appears that the whole building, with its chimney, had been lifted bodily and twisted round and round. The kitchen floor separated itself from the rest of the house and travelled over a boxthorn hedge a distance of 100 yards. All that remained was part of the veranda floor, that of the sitting-room resting on the hedge.

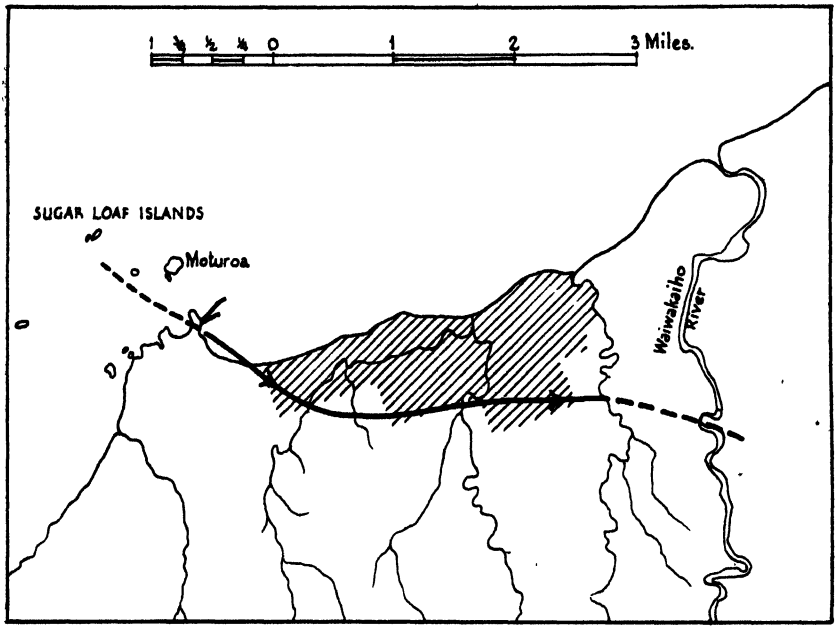


FIGURE 4. TORNADO TRACK: NEW PLYMOUTH, 17TH MAY, 1934.

Outer and inner walls were moved about 20 yards, while roofing material lay strewn various distances up to a mile away. The heavy concrete block supporting the kitchen stove was torn from its foundations and moved a few feet, while the stove itself was turned wrong way round. The path of this storm was 2 miles long with a width of 200 yards. Torrential rain was falling at the time.

7. *Mokai* (5th January, 1938, at 1.15 p.m.).—With a deafening roar a tornado struck a timber company's settlement, tearing off corrugated-iron roofing from two mill buildings, sending sheets flying through the air for upwards of 100 yards, and piercing other buildings. Many heavy beams were displaced. Almost simultaneously four of the workmen's cottages came within the narrow trail of the whirlwind and were razed to the ground, leaving only piles of splintered timber, broken windows, and household effects.

8. *Kaitaia* (26th August, 1942, at 10.45 a.m.).—This was probably the worst tornado on record, certainly so from the point of view of injuries received. One boy was killed by flying objects and eight people required hospital attention. The visitation was preceded by thunder and heavy hail and followed by light rain. After leaving a trail of destruction at Waipapakauri the tornado changed its course, tearing out trees near Awanui, travelled through the main street of Kaitaia, and finally spent itself out when it entered the hills in the south toward Takahue. Roofs and verandas of most buildings in the main street collapsed or disappeared. Roofing, iron was carried up to 2 miles away. Damage caused in the town occurred

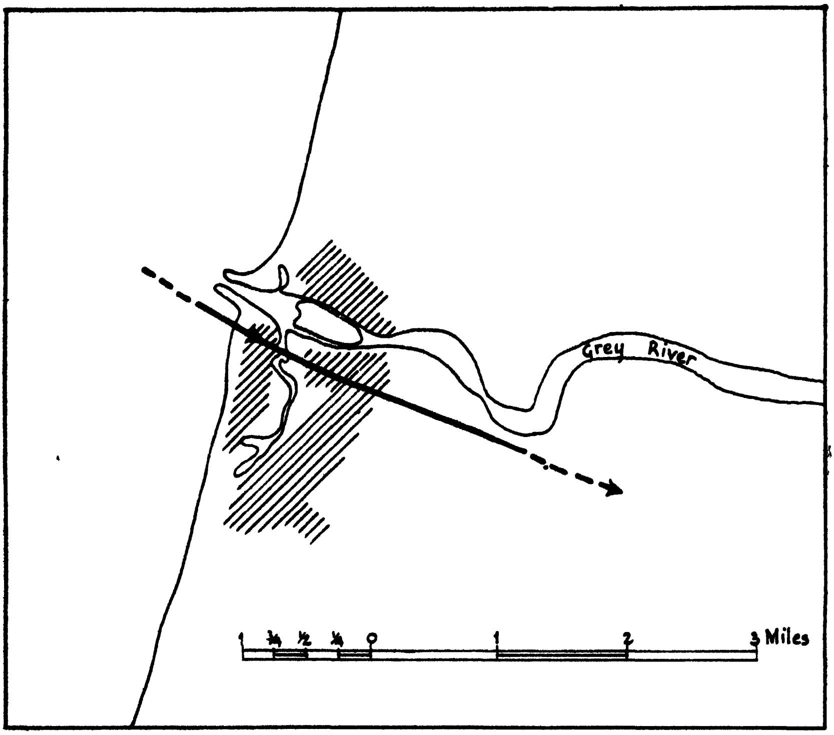


FIGURE 5. TORNADO TRACK. GREYMOUTH, 29TH MARCH, 1936.

within five seconds, but a roaring noise continued for two minutes. One house in the Awanui Road was lifted and completely turned round and dashed to pieces.

Something of the destructive vigour of our worst tornadoes can be gathered from the foregoing accounts. In an individual case the area actually affected is so small that tornadoes, compared with other possible disasters, constitute an insignificant hazard to life and property. No unnecessary risks should be taken, however, and at the sign of approach of a funnel cloud, perhaps accompanied by an ominous roar, one should lie down in a ditch or other depression, or seek shelter in a solidly constructed building should one be at hand.

REFERENCE

KIDSON, E., and THOMSON, A. (1931): *N.Z. J. Sci. & Tech.*, *12*, 193–206.

A USEFUL LABORATORY VACUUM-TUBE VOLT-METER

By W. G. WHITTLESTON and J. M. ZIMAN, Animal Research Division, Ruakura, Department of Agriculture

[*Received for publication, 21st August, 1945*]

SOME time ago one of the writers (J. Z.) was examining the possible use of cathode-follower circuits as a basis for a photometer. The "long-tailed pair" circuit was tried(1, 2) and showed promise. A vacuum-tube volt-meter was needed at the time, so, using the divider circuit described by

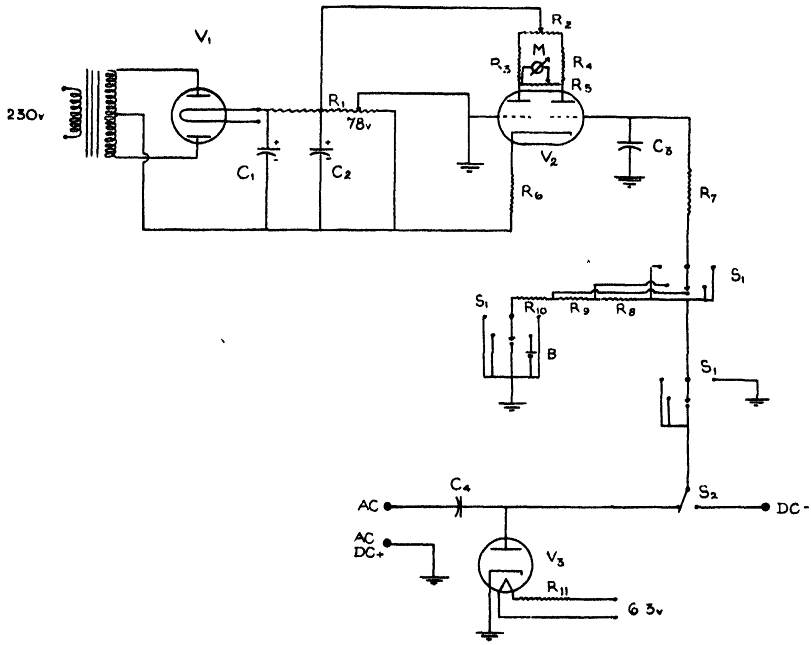


Fig. 1—List of Components

R_1: 22,500 voltage divider tapped at 2,500 ohms and at a point giving 78 volts above the transformer centre tap.
R_2: 5,000 ohm potentiometer. (Zero adjustment.)
R_3R_4: 75,000 ohm resisters.
R_5: 5,000 ohm potentiometer. (Scale adjustment.)
R_6: 20,000 ohm resister.
R_7: 4 megohm resister.
R_8: 9 megohm resister.
R_9: 0·9 megohm resister.
R_{10}: 0·1 megohm resister.
R_{11}: 17 ohm resister.
C_1C_2: 8 mfd. tubular electrolytic condensers.
C_3: 0·05 mfd. mica condenser.
C_4: 0·01 mfd. mica condenser.
S_1: Three-circuit five-position rotary switch.
S_2: Single-pole double throw switch.
V_1: 5Z4 (or 5Y3G) rectifier.
V_2: 6N7 twin triode.
V_3: 6H6 double rectifier with the two diodes in parallel.
M: 0–1 milliameter.
B: Cadmium cell.

Thurston(3), the circuit shown in Fig. 1 was constructed. The device has been so useful that its original form has continued in use without refinement. There is no great novelty in the "long-tailed pair" circuit, but it is very useful, very stable, and not as well known as it deserves to be. In fact, it was only when the writers encountered the paper by Buras and Reid(4), long after the construction of the meter here described, that its full value was realized. Buras and Reid used the circuit in a titrimeter capable of operating with a glass electrode.

The use of a " home-made " Weston cadmium cell as an internal standard together with the inherent stability of the double cathode follower circuit make the instrument very useful when a long " warm-up " period must be avoided. (It may be used five minutes after switching on.)

With the half-wave rectifier V_3 used it was found essential to use 17 ohms in series with the heater to reduce the error due to potential caused by the initial velocity of the electrons emitted from the cathode. The resistance is best found experimentally as it will vary with different tubes. Using regulated voltage for heaters and plate supply the meter would be exceptionally stable. Even as it is, for general laboratory use where precision is secondary to convenience and cheapness the usual mains fluctuations have not caused any trouble. Readings can quickly be checked against the standard when accuracy is essential. Further, the use of a robust 0–1 milliameter makes the instrument both cheap and reliable.

Three ranges are used—0–2, 0–20, and 0–200 volts A.C. or D.C.—the readings on A.C. being, of course, peak voltages. The instrument is substantially linear in characteristics over the ranges used which simplifies calibration.

REFERENCES

(1) RICHTER (1943): *Electronics, 16,* 11, 112.
(2) COCKRELL: "Industrial Electronic Control" (McGraw Hill), p. 113.
(3) THURSTON (1943): *Electronics, 16,* 10, 102.
(4) BURAS and REID (1945): *Industrial and Engineering Chemistry (Anal. Ed.), 17* 2, 120.

THE NEW ZEALAND

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CHRYSOTILE ASBESTOS DEPOSITS, FLORA SURVEY DISTRICT, NORTH-WEST NELSON

By W. E. HALL and J. J. REED, New Zealand Geological Survey, Department of Scientific and Industrial Research

[*Received for publication, 13th September, 1945*]

Summary

In the Flora Survey District, asbestos is present in serpentinite as slip- and cross-fibre, the latter type being the more important. The individual cross-fibres are usually less than ¾ in. in length, although longer fibres (up to 3 in.) occur locally. The most valuable deposit so far discovered is in the flat area between Gabbro and Asbestos creeks, where a small solid block of serpentinite is traversed by a continuous network of narrow (½ in.) asbestos veins. A "spheroid" occurrence of asbestos is developed on the western slopes of the area, but systematic mining of this does not appear possible. Further prospecting is required before the total workable quantity of asbestos can be estimated.

INTRODUCTION

Location.—The asbestos deposits described in this report occur in the upper reaches of the Takaka River, in Flora Survey District, about twenty miles S.S.W. of the township of Takaka in north-west Nelson (Fig. 1). The area examined during three weeks of February and March, 1945, comprised the major part of the lease (approximately 1,000 acres) owned by Hume Pipe Co. (Fig. 1); the boundaries were Takaka River to the east, Gabbro and Camp creeks to the north and south, and the bush-line to the west.

Accessibility.—Previously the only means of access to the asbestos claim was by way of two pack-tracks, one route leading over Pearse Saddle from Pokororo on Motueka River, and a second route via Barron Flat starting at Upper Takaka. Recently, however, the Upper Takaka - Cobb Power-house road has been extended up Takaka River as far as the claim. Electric power is available at the claim from the Cobb Valley hydro-electric scheme.

Topography.—The area is drained by Takaka River with its westerly tributaries, Gabbro, Asbestos, and Camp creeks. The immature Takaka River occupies a narrow gorge, the eastern wall of which is a precipitous bluff approximately 800 ft. high. To the west the land rises to the 3,000 ft. contour, the continuity of the slope being interrupted by a comparatively flat area upon which the main asbestos workings are situated (Fig. 2). The area west of Takaka River, except for the lower slope, has been mainly cleared of bush.

Previous Work.—The first reference to chrysotile asbestos in the Flora Survey District was given by W. Gibbs (1889), and in 1911 a report on the mining operations in progress was published by C. H. Holland. Later,

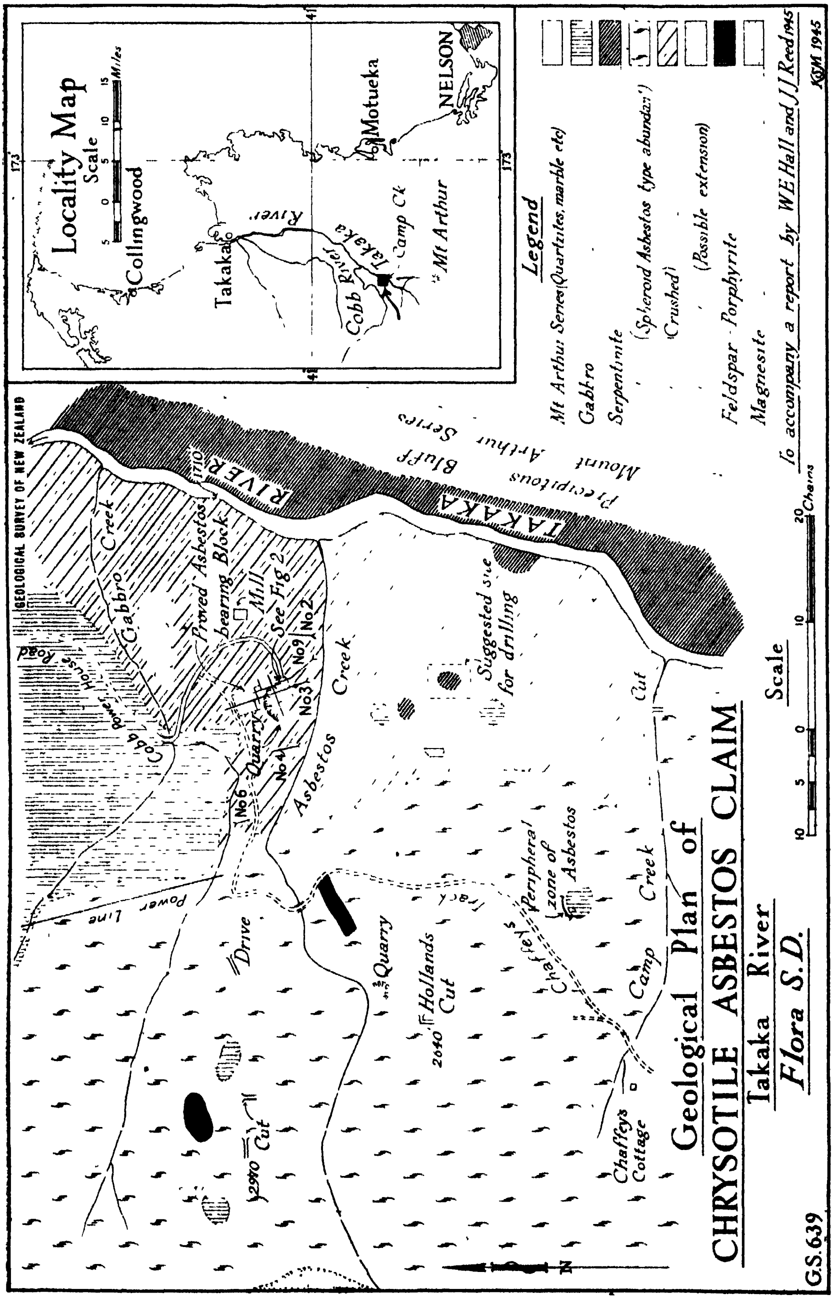

Fig. 1.—Geological map of asbestos claim, Takaka River, Flora Survey District; inset, locality map.

Dr. Henderson (1923) described the asbestos deposits and discussed their origin; more recently a magnetic survey of the area was carried out by W. M. Jones (1939).

GENERAL GEOLOGY

The rocks of the district may be divided into—

(a) Palæozoic sedimentary rocks with some igneous material.

(b) Ultrabasic and basic intrusions which have been injected into the Palæozoic series.

The Palæozoic rocks have been subdivided by Dr. Henderson and others* into the Mount Arthur or Upper Aorere Series (Upper Ordovician ?) and the Haupiri Series possibly Silurian in age. The rocks forming most of the 800 ft. bluff to the east of Takaka River belong to the Mount Arthur Series, which includes quartzites, grey and black phyllites, marbles, chloritic schists, and altered igneous rocks. The Haupiri Series of breccias, greywackes, &c., occurs to the north and west of the area here examined.

FIG. 2.—View of asbestos claim looking north-east. The asbestos-bearing zone between Asbestos and Gabbro creeks is in the middle distance, a bush-covered precipitous bluff in background.

Ultrabasic and basic rocks are typically intimately associated with each other in this area, where lenses and dykes of the gabbroic types liberally occur with rocks of the more basic type. The basic rocks are mainly pyroxenite and gabbro, but feldspar-porphyrite dykes are abundantly developed ; the gabbros are further differentiated into dark and light coloured fractions. All these rocks have been hydro-thermally altered to some extent, the main effects noted being uralitization and chloritization of the pyroxene, saussuritization of the feldspar with epidotization of the rock as a whole. In the pyroxenites, lime metasomatism has produced a garnet-rich rock comparable with the "rodingite" of Nelson (Grange, 1927) ; on the other hand, serpentinization of the pyroxenites with occasional asbestos formation is not uncommon. A basalt dyke in the pyroxenite has been reported by Dr. Henderson (1923B, p. 186), but a question of nomenclature appears to be here involved.

* Published maps of the Motueka Bulletin which has not yet been printed.

The peridotitic differentiate, as far as the writers are aware, has been completely serpentinized to chrysotile, bastite, and to an antigorite-like serpentine which, however, lacks the typical thorn structure so well developed in antigorite rocks of the Mikonui area (Morgan, 1908, p. 122) and elsewhere. Two types of serpentinites* have been distinguished in the field (Henderson, 1923B, p. 185 ; Jones, 1939, p. 139) ; one type forms prominent outcrops and exhibits rough weathering surfaces stained red and brown, whereas a smooth surface, usually whitish in colour, is characteristic of the other type. It has been suggested by W. M. Jones (1939, p. 140) that the red serpentinite " zone " is the remnant of a marginal shell of the serpentinite body adjacent to the contact with the intruded sedimentaries. This postulates, however, a position of the sedimentaries for which field evidence is lacking. Moreover, the two distinctive types of weathering have been recognized in serpentinites in many other areas where there is no question of contact with overlying beds—*e.g.*, the Great Serpentine Belt of New South Wales (Benson, 1913,

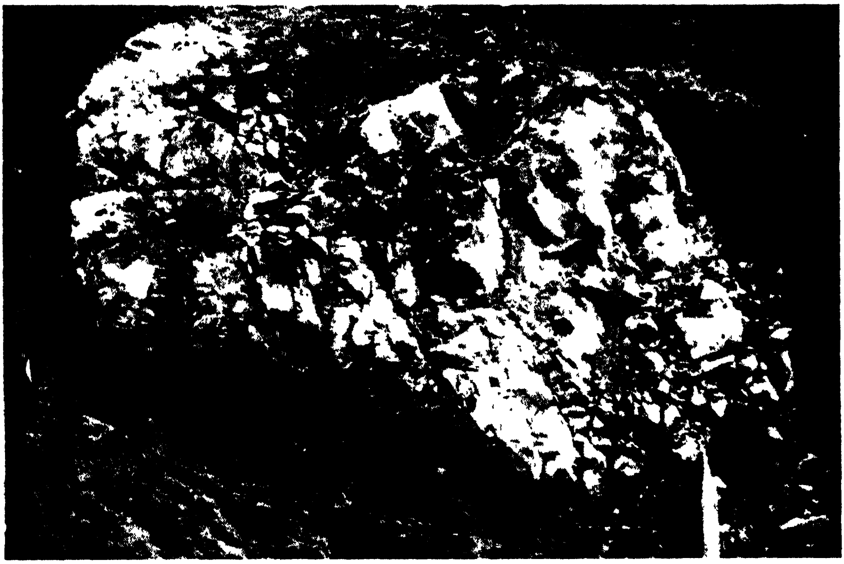

FIG. 3.—Faulted " rodingite " lense in asbestos-bearing zone between Asbestos and Gabbro creeks ; a vein of asbestos surrounds the lense.

p. 671). Analyses quoted by Dr. Henderson (1923B, p. 187) indicate that the " white " type is more purely magnesian than the type weathering to a red crust. Further study is required, but a possible explanation suggested by Dr. C. O. Hutton is that the weathering expresses textural and mineralogical differences resulting from the shearing of the serpentinites. Talc-magnesite and quartz-magnesite rocks (Wellman, 1942, 1943) are common ; they occur in large boulders present in the vicinity of the lower part of Gabbro Creek and *in situ* on the western boundary of the area under review.

Structure.—The basic and ultrabasic rocks are considerably fractured and faulted by movements post-dating the period of serpentinization (Fig. 3). In the relatively flat area between Asbestos and Gabbro creeks an intensely shattered body of asbestos-bearing serpentinites is present. Parallel faults striking 25° west of north are suggested by the occurrence of downward-stepping blocks of serpentinite in the higher part of the area.

* Following Lodochnikow (1933, p. 728), serpentinite is used to denote rocks consisting almost exclusively of minerals of the serpentine group.

CHRYSOTILE ASBESTOS

Slip-fibre.—Slip-fibre is irregularly distributed, generally in aggregates (less than 5 in. in length) of very short fibres lying parallel to and within the planes of shearing in the serpentinite. A mill test of 405 lb. of hand-picked slip-fibre from Holland's Cut proved very disappointing, yielding only 1 lb. of ungraded fibre. No further reference will be made to slip-fibre, though it should be understood that this form may make a contribution to the total output of fibre.

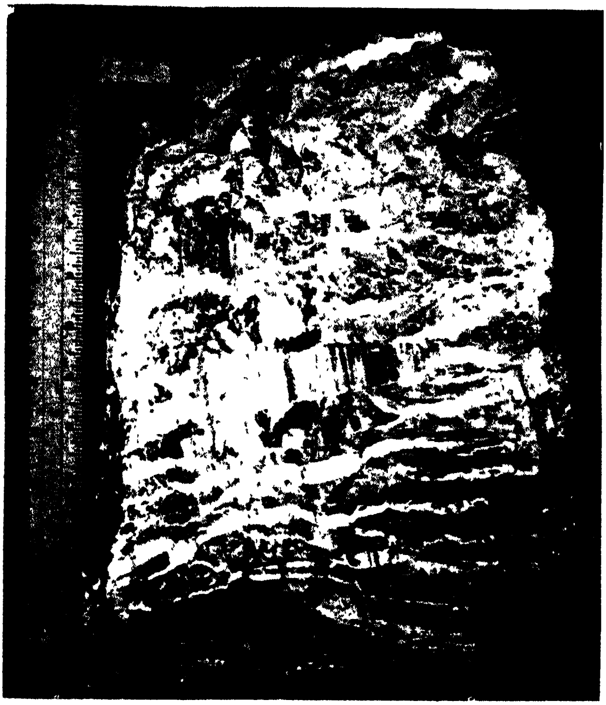

FIG. 4.—Asbestos-rich shell ("spheroid" type) which surrounds a larger core of barren serpentinite.

Cross-fibre.—Three modes of occurrence can be distinguished for veins of cross-fibre, the individual fibres of which are more or less perpendicular to the vein walls:

(*a*) *The "Boulder" or "Spheroid" Type.*—This type, abundantly developed on the western slopes of the area examined, has been described by Dr. Henderson (1923A, p. 121). Although some up to 3 in. have been found, the asbestos veins are usually less than $\frac{3}{4}$ in. wide, and are arranged in ribbon fashion around spheroidal or pillow-shaped masses of serpentinite which range from a few feet to a chain or more in diameter. The vein-bearing zone (Fig. 4) forms a shell (6 in. to 30 in. thick) surrounding a core of serpentinite in which few or no veins are present. Cuts (less than 100 ft.) have been made in this area, but only barren fractured serpentinite has been encountered.

(*b*) "*Contact*" *Type.*—An asbestos-rich zone is usually present at the contact of serpentinite with gabbro lenses. In the crush-zone between Gabbro and Asbestos creeks, veins of asbestos form peripheral zones surrounding gabbro lenses or "boulders" (Fig. 3); W. M. Jones (1939, p. 126) has described another occurrence 30 chains north-east of Mr. Chaffey's cottage. The maximum observed width of this zone is 2 ft., but generally it is only a few inches wide.

(*c*) The most important asbestos so far discovered is in the flat area between Asbestos and Gabbro creeks, where prospecting revealed a solid block of serpentinite traversed by a continuous network of narrow (less than $\frac{1}{8}$ in.) asbestos veins (Fig. 5). This block is surrounded by intensely crushed serpentinite in which nearly all the fibre is destroyed. Alteration of the fibre to talc has been observed in the crushed material and rarely in the solid serpentinite block.

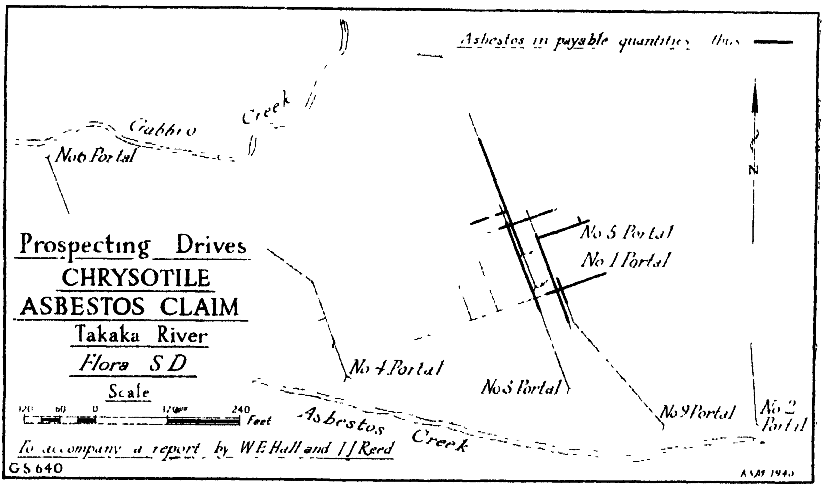

Fig. 5.—Plan of prospecting carried out between Asbestos and Gabbro creeks.

Origin.—Although a detailed discussion of the origin of the asbestos is outside the scope of this paper, several points may be noted. It is now generally agreed that serpentinization of peridotites is an autometasomatic alteration occurring during the same cycle of igneous activity as the injection of the ultrabasic magma. In other words, "the ultra-basic stews in its own juice" (Hess, 1918, p. 635). This fact has an important economic application, since the Flora serpentinites (with associated asbestos) may be expected to continue to depth. In the Flora district, solutions or fluids from the ultrabasic magma in excess of that required for serpentinization appear to have formed asbestos in joints produced at the completion of serpentinization of the peridotite, in partings at serpentinite-gabbro contacts, and in fractures resulting from tensional stress. The formation of a continuous network of asbestos veins such as is described in type (*c*) above seems related to the presence of a closely spaced fracture system in the serpentinite, whereas fracturing produced by tensional stress does not appear to be so dominating a factor in the more localized asbestos occurrences of the "spheroid" and "contact" type.

Quantity.—Although insufficient data on quantity are available, a small economically important block (approximately 300 ft. by 80 ft.) has been proved in the crush-zone between Asbestos and Gabbro creeks. Asbestos of the "spheroid" type is developed abundantly on the western slopes of the area, but it appears to be too irregular for systematic mining. Further, promising asbestos outcrops have been reported (Henderson, 1923A, p. 121) in the serpentinite region outside the area examined in this report.

It is pertinent to inquire into the experience gained in South Africa and Canadian asbestos fields about conditions at depth. F. F. Keep (1931, p. 3) states: "It is extremely rare (in Southern Rhodesia) for chrysotile asbestos deposits to show any general change in quantity or length of fibre at depth, the average values in succeeding zones at depth being remarkably constant." In the Thetford district of Quebec "core-drilling to depths greater than 1,700 ft. has revealed the presence of fibre comparable in quantity and quality with that in the present workings" (*Bureau of Mines*, 1939, p. 34). The following statement of mining operations at King Pit, Thetford district, may be applicable: "A system of underground mining has been developed, 3,000 ft. of drifts and cross-cuts driven and seven stopes opened up. Costs of underground mining compare favourably with open-pit work, winter work is more steady and the finished fibre contains less wood" (Ross, 1931, p. 31).

The writers consider that the prospecting to date is inadequate for the assessment of the asbestos deposits as a whole. Further investigation is required to indicate the full extent of the asbestos-bearing block or blocks in the crush zone between Asbestos and Gabbro creeks, and to show whether this crush zone extends southward between Camp and Asbestos creeks. A drill-hole situated, for example, near the red weathered serpentinite between Asbestos and Camp creeks (Fig. 1) would reveal the nature of the underlying rock and indicate whether additional drilling would be required. If drilling is considered too difficult, however, the driving of adits would be efficient, as shown by the prospecting carried out between Asbestos and Gabbro creeks. An unknown factor is whether the alteration of fibre to talc which has been observed rarely in the asbestos-bearing block between Asbestos and Gabbro creeks becomes more widespread at depth. More magnetic observations may give assistance, for W. M. Jones (1939) was able to demonstrate that a large magnetic anomaly exists over the asbestos-bearing block between Asbestos and Gabbro creeks. Although admittedly the prospects are not bright, the "spheroid" type of asbestos should be explored. Asbestos outcrops outside the serpentinite area examined in this report should be investigated.

Quality.—An analysis of the "spheroid" type of asbestos is compared with Canadian and South African fibre in Table I. The Dominion Analyst reported that fibres embedded in fire-clay and heated in a crucible in a coke-furnace to a temperature of 1,530° c. showed no sign of fusion, although the colour had changed to a pale-yellowish shade; fibres readily fused in the blow-pipe flame (Henderson, 1923B, p. 190).

Uses.—Although a complete inventory of the uses to which asbestos can be put is not possible here (a complete list is given by Ross, 1931, pp. 125–32), some of the more important products in which it is incorporated can be listed: automobile brake-band linings, heat insulation materials, and building materials such as wallboards, corrugated sheeting, and tiles. For the latter uses, short non-spinning grades of fibre are mainly employed; the fibre of the Flora Survey District is mostly of this type.

ACKNOWLEDGMENTS

Gratitude is expressed to the Hume Pipe Co. for assistance with transport and accommodation; the hospitality extended by Mr. and Mrs. Chaffey was also appreciated. Acknowledgment is made of the assistance of Dr. C. O. Hutton in the preparation of this paper.

TABLE I.—ANALYSES

	(1)	(2)	(3)
Silica (SiO_2) ..	41·97	39·42	42·15
Alumina (Al_2O_3)	1·13	0·72	0·58
Ferric oxide (Fe_2O_3)	1·14	2·13	1·45
Ferrous oxide (FeO)	0·63	1·07	0·96
Magnesia (MgO)	40·53	43·07	40·76
Lime (CaO) ..	0·04	Nil	Nil
Potash (K_2O) ..	None	..	N.d.
Soda (Na_2O) ..	None	..	N.d.
Water above 105° c.	12·59	13·57*	13·11
Water below 105° c.	2·13	..	0·92
Carbon dioxide (CO_2)	None	..	Nil
Titanium dioxide (TiO_2)	0·04	..	N.d.
Zirconium dioxide (ZrO_2)	None	..	..
Phosphorous pentoxide (P_2O_5)	None	..	N.d.
Sulphur (S) ..	Trace	..	Trace
Chlorine (Cl) ..	..	..	Trace
Chromium trioxide (Cr_2O_3)	None	Trace	N.d.
Manganous oxide (MnO)	0·07	..	0·10
Nickel oxide (NiO)	0·13	..	0·17
Baryta (BaO) ..	None	..	..
Strontia (SrO) ..	None	..	..
	100·40	99·98	100·20

* The figure represents combined water after all samples were dried at 105°c.

(1) Chrysotile asbestos ("Spheroid Type"), Flora Survey District. Analyst, F. T. Seelye (Henderson, 1923B, p. 187).

(2) Chrysotile asbestos, Thetford District, Quebec. Average of eleven analyses. Analyst, E. A. Thompson (Ross, 1931, p. 20).

(3) Chrysotile asbestos, Belingwe District, Southern Rhodesia. Analyst, E. Golding (Keep, 1929, p. 118).

REFERENCES

BENSON, W. N. (1913): The Geology and Petrology of the Great Serpentine Belt of New South Wales, Pt. III. *Proc. Linn. Soc. N.S.W.*, *38*, 662–724.

COOKE, H. C. (1936): Asbestos Deposits of Thetford District, Quebec. *Econ. Geol.*, *31*, 355–76.

DRESSER, J. A. (1913): Preliminary Report on the Serpentine and Associated Rock of Southern Quebec. *Mem. Geol. Surv., Canadian Dept. of Mines*, *22*.

GIBBS, W. (1889): "The Mining Industry." C.–2, 109.

GRANGE, L. I. (1927): On the "Rodingite" of Nelson. *Trans. N.Z. Inst.*, *58*, 160–6.

HENDERSON, J. (1923A): Chrysotile Asbestos in the Upper Takaka District, *N.Z. J. Sci. & Tech.*, *6*, 120–3.

——— (1923B): Notes to accompany a Geological Sketch Map of the Mount Arthur District. *Ibid.*, 174–90.

HESS, H. H. (1933): The Problem of Serpentinization and the Origin of certain Chrysotile Asbestos, Talc, and Soapstone Deposits. *Econ. Geol.*, *28*, 634–57.

HOLLAND, C. H. (1910–11): The Takaka Asbestos Deposits, Nelson, New Zealand. *Mining and Engineering Review*, *3*, 477–79.

JONES, W. M. (1939): Magnetic Observations of Nelson Serpentinites with Remarks on the Geology of the Asbestos Deposits. *N.Z. J. Sci. & Tech.*, *21*, 128B–142B.

KEEP, F. E. (1929): The Geology of the Shabani Mineral Belt, Belingwe District. *Bull. Geol. Surv. South Rhodesia*, *12*.

——— (1931): Some Practical Hints in connection with Chrysotile Asbestos. *Trans. Geol. Soc. South Africa*, *33*, 1–4.

LODOCHNIKOW, W. (1933): Serpentines and Serpentinites and the Petrological Problems Connected with Them. *Problems of Soviet Geology*, *No. 5*. (German summary, 728–70.)

ROSS, J. G. (1931): Chrysotile Asbestos in Canada. *Rept. Mines Branch Canadian Dept. Mines*, 707.

Staff, Bureau of Mines (1939): "The Canadian Mineral Industry in 1938." (Asbestos.) *Bureau of Mines, Canada*, 804.

WELLMAN, H. W. (1942): Talc-magnesite and Quartz-magnesite Rock, Cobb-Takaka District. *N.Z. J. Sci. & Tech.*, *24*, 103B–127B.

——— (1943): Talc in North-west Nelson and North Westland. *N.Z. J. Sci. & Tech.*, *24*, 227B–235B.

LIMESTONE AT MOTATAU

By J. HEALY, New Zealand Geological Survey, Department of Scientific and Industrial Research

[*Received for publication, 3rd September, 1945*]

Summary

A brief description is given of a block of limestone a little over 40 acres in area. The area is part of the largest single limestone block in North Auckland, and is situated at Motatau, some twenty-three miles north-west from Whangarei. The rock is hard, flaggy limestone striking north-east and dipping at high angles to the north-west, and is overlain unconformably on the higher ridges by younger sandstones.

Six specimens were collected and analysed, giving a content of calcium carbonate ranging from 41 per cent. to 70 per cent. At the northern end, 2,500,000 tons of limestone containing from 63 per cent. to 70 per cent. calcium carbonate are available, and 4,000,000 tons containing less than 60 per cent. calcium carbonate in the southern part, all with practically no overburden.

THE writer visited the area on the 27th and 29th March, 1945, to make a geological survey of the limestone deposit and collect samples for analysis. As the exact location of the area previously surveyed was not known, pegs were located along the back boundary, and these were surveyed in by chain and compass, and are shown in the plan. No pegs were found on the railway boundary, so a boundary has been assumed which gives a slightly greater area than the correct one, but this does not affect the quantity of limestone, as the boundary in question runs along land which is not limestone.

Location.—The correct area of 41 acres 3 roods 29 perches forms part of Motatau No. 2 Block, Section 49A 2, which immediately adjoins Motatau Railway-station on the east side. The limestone area lies in the south-west corner of the above section, and is bounded on the west by the railway, on the south by the southern boundary fence of the same section, on the east by a fence alongside pegs IX, VIII, VII, VI, and V, then on the east and north by lines through pegs V, IV, III, II to another on the railway boundary not located by the writer.

In this report, and as shown in the plan, the northern boundary meets the railway fence at the northern toe of the first ridge south of Motatau Railway-station, through which a cutting passes. The point of contact is the first post south of the new drain here, and a datum level of 170 ft. above sea-level was assumed for this point.

The northern end of the limestone deposit is within one-quarter of a mile south of the Motatau Station, and at its nearest point 3 chains east of the railway-line. Motatau is thirty-two miles by rail from Whangarei and twenty-one miles from Opua. By road the deposit is reached by leaving the main north highway at Maromaku.

Topography.—The limestone forms a ridge trending a little west of north, parallel to the railway-line and to the east of it. Two spurs project west across the railway, which passes through them in cuttings, the northern spur being of sandstone and the southern of limestone. Between them is a grassy flat averaging 2 chains in width and paralleling the railway for 10 chains; south of the southern spur is a swampy flat, half the area of the former. Beyond the spurs and flats the ridge rises steeply to a height of 596 ft. above sea-level at 20 chains east of the railway in the south, and to 391 ft. at 8 chains east in the north.

Drainage from the area crosses the railway to swampy ground on the west bordering the Ramarama Stream, which flows north to the Kawakawa River. The block is divided into two topographic units by a gully in which a small stream flows south-west across the area. North of this gully the limestone reaches to the top of the ridge at

391 ft. above sea-level. To the south, the ridge, which reaches 596 ft. above sea-level, is capped by sandstone. The eastern boundary of the southern block lies along the crest of the ridge of sandstone. The eastern boundary of the northern block follows a fork of the dividing gully cut into limestone, and the northern boundary cuts across a saddle of limestone separating the block from rising limestone ground to the north.

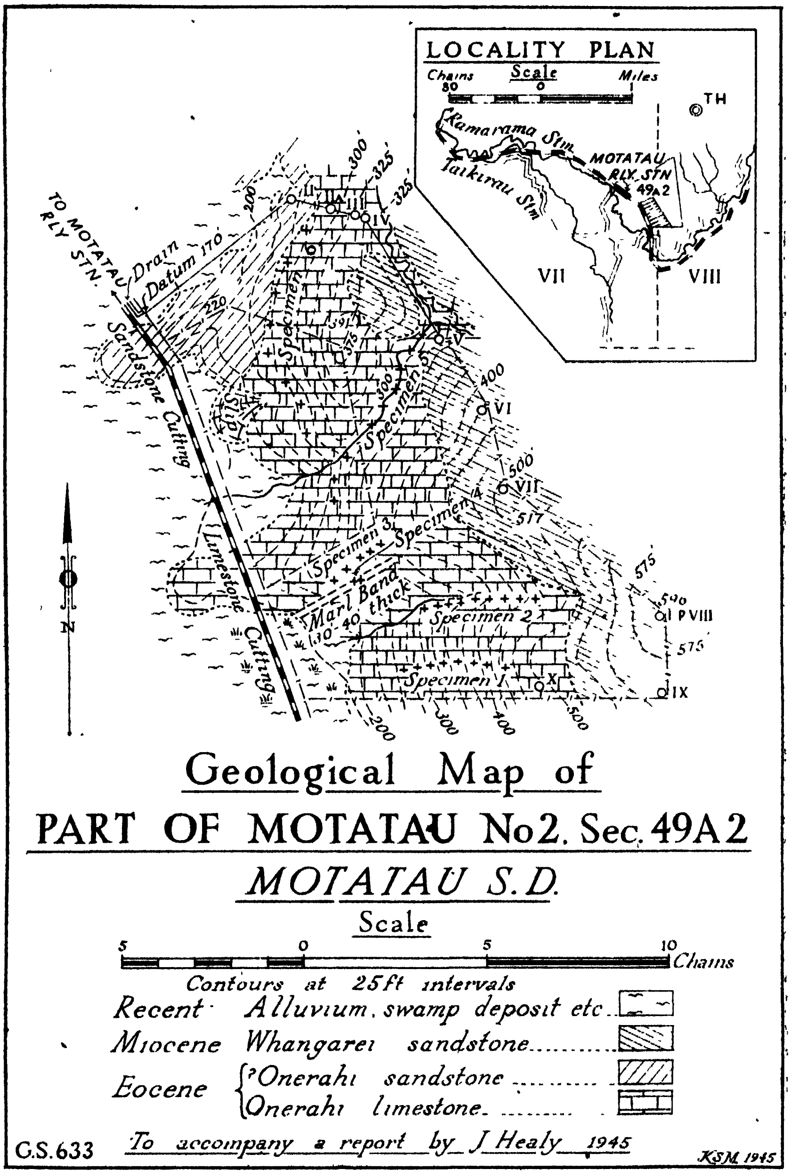

FIG. 1.

The northern block is fringed on the north by lower slopes of sandstone which run west as a low spur mentioned above. The limestone slopes are steep. The southern block is partly cut by a gully, dry in the upper half, which drains west into the southern, swampy flat, and heads back into the sandstone at a point where it overlies the limestone at approximately 500 ft. above sea-level.

GEOLOGY

The limestone is the oldest rock present, and is regarded as belonging to the Onerahi Series of Eocene age, or perhaps slightly older. The beds strike north-east and dip north-west at angles of from 60° to vertical. The limestone is hard and flaggy, varies from grey to greyish-white in colour, and has undergone intense folding. It is closely intersected by joints. A marly phase was found interbedded with the harder limestone in the southern block and is shown on the map. The minimum vertical thickness of the limestone beds exposed in this area is 1,400 ft.; and the total thickness extending into the area to the south may be several times this amount.

To the north-west, within the area under discussion, the limestone passes up into sandstone, a weathered variety of which may be seen in the railway cutting. Its relationship with the limestone is not known and was not investigated, but from the topographic appearance it overlies the limestone with similar disposition, so it has been classed *pro tem* as an upper facies of the Onerahi Series.

A fine-grained sandstone overlies the limestone highly uncomformably, and is identical with similar sandstones in adjacent districts which have been referred to the Whangarei Series. The sandstone forms a strip varying from 3 chains to 5 chains in width within the eastern margin of the southern block. Another patch, 3 chains by 4 chains, rests on the eastern slopes of the northern limestone block, but is probably not more than 10 ft. in thickness. The surface of the limestone prior to the deposition of the Whangarei sandstone was apparently extremely irregular, as the contact varies from 500 ft. above sea-level near peg IX to 320 ft. above sea-level at peg V.

Similar conditions hold for the surrounding district, where most of the ridges reaching to comparable levels are capped with residual remnants of Whangarei sandstone. The sandstone apparently formerly extended over the entire area, but has been removed by erosion from all but the higher and broader interfluves.

The swampy conditions of the Ramarama Stream have been caused by alluviation following obstruction by basalt flows in the Kawakawa valley and/or subsidence of the land generally.

QUALITY OF THE LIMESTONE

Six samples were taken from the area. In each case a composite sample was obtained by taking a series of small specimens from a face or line, and the location and extent of each specimen is shown on the map. It was thus expected that analysis of each sample would give an average quality of the rock for the zones of collection. The analyses were carried out by Mr. Arnold, Department of Agriculture, Whangarei, and the results, which are expressed as percentage of calcium carbonate of the whole, can be safely assumed to be within 2 per cent. correct:—

Sample 1, from limestone face, 2 chains north of south boundary: 61 per cent. calcium carbonate.

Sample 2, from upper part of dry gully in southern block: 60 per cent. calcium carbonate.

Sample 3, from main spur, southern block: 58 per cent. calcium carbonate.

Sample 4, from marly phase, main spur, southern block: 41 per cent. calcium carbonate.

Sample 5, from gully between north and south blocks: 63 per cent. calcium carbonate.

Sample 6, from entire west face, nothern block : 70 per cent. calcium carbonate.

It would thus appear that the quality of the rock improves towards the highest horizons of the limestone. To east-west spurs and the gullies are adjusted to the structure of the limestone, and the main spur of the southern block appears to be caused by an especially resistant strata of the limestone, from which sample 3 was taken. Between the marly band from which sample 4 was taken and the gully to the south, much of the slope is masked by surface material slipping down the slope, and outcrops of hard limestone are not so conspicuous as elsewhere, so there is every possibility that there is further development of the marly phase there. The rock between the outcrop of marl and the gully is almost certain to contain less than 60 per cent. of calcium carbonate.

It is evident, therefore, that the limestone of the southern block is likely to average at the very most 60 per cent., and in all probability less. Much of the northern block, on the other hand, is likely to average from 65 per cent. to 70 per cent. of calcium carbonate.

These results are, on the whole, unpromising, and before any large-scale attempts are made to work the deposit as a whole it would be desirable to prospect further by open cuts or bores.

Quantity of Limestone available

It is estimated that a minimum quantity of 2,500,000 tons of limestone between 63 per cent. and 70 per cent. is available from the northern block, on the assumption that the rock is quarried to the level of the 200 ft. contour.

To the same level through the southern block, it is estimated that at least 4,000,000 tons of limestone of 60 per cent. and less are available, back to the edge of the Whangarei sandstone.

Overburden

Over most of the area the overburden is practically nil, as bare rock projects through the surface at frequent intervals.

The patch of Whangarei sandstone resting on the eastern slopes of the northern block is not very thick, and is likely to be less than 10 ft.

The northern slopes of the gully in the southern blocks are masked by loose surface sandstone and limestone slipped from above to an unknown depth not likely to be more than a few feet. Otherwise the upper levels of the limestone are covered in between outcrops by thin overburden of a few feet only.

The lower slopes of the limestone area are likely to be masked by slipped material to an unknown depth.

Without any exact information on the points above it would be impossible to assess a figure for quantity of overburden, but, on the whole, it can be said to be extremely light.

Other Limestone Deposits

Within several miles of Motatau, both alongside and away from the railway, are extensive deposits of the limestone similar in nature to that described in this report. These are unmapped, and the writer has no knowledge of the quality of the limestone. Further investigation would be necessary to determine these points, but in deciding to open up a large quarry they should be borne in mind.

TAKAKA COALFIELD

By H. W. WELLMAN, New Zealand Geological Survey, Department of Scientific and Industrial Research

[*Received for publication, 13th September, 1945*]

Summary

The geology of the Takaka coalfield is described, special mention being made of the structure, which is well defined by limestone outcrops. Plans and cross-sections illustrating the geology and structure are presented and suggestions made for testing the deeper parts of the field.

INTRODUCTION

THE township of Takaka lies on the east bank of the Takaka River, about four miles from its mouth, and is the centre of a small, rich farming district roughly co-extensive with the coalfield. Access to the coalfield is good and no part of it is more than a mile from a formed road. Outlying settlements within the coalfield are the coastal villages of Motupipi and Pohara and the cement-works at Terakohe. Coal has been worked in a desultory manner in the Takaka district for nearly a hundred years to produce a few thousand tons of open-cast and shallow-dip coal from thin seams. The coal is sub-bituminous and has a medium to high sulphur content. Mapping was done on a scale of 20 chains to an inch and was based on the excellent topographic map published with the *N.Z.G.S. Bulletin No. 3.*

TOPOGRAPHY AND DRAINAGE

The coalfield rises only a few hundred feet above sea-level and lies at the north end of the Takaka Valley, a tectonic depression between the Haupiri and Pikikiruna ranges. The Takaka River flows north to Golden Bay near the middle of the depression, being joined within the coalfield by the Waingaro, Anatoki, and Waikoromumu rivers, three large streams that flow east from the Haupiri Range. On the other side of the valley the steep but even western scarp of the Pikikiruna Range has not been greatly modified by the small streams that cascade down it before pursuing meandering courses over the Takaka Valley. The length of these sub-parallel streams decreases north-eastward; Rameka Creek and Dry River, which flow into the Takaka and Motupipi rivers respectively, being the longest. Kitty, Gibson, and Ellis creeks flow into the Motupipi estuary, and Winter Creek, the smallest and most easterly, flows direct to Golden Bay. The central part is drained by the Motupipi River, a small stream that flows north-east from the township of Takaka and reaches Golden Bay as a shallow tidal estuary. The coast of Golden Bay, the north-eastern limit of the coalfield, is only five miles long, but varied. On the west side, at Waitapu Hill, the undermass rises nearly 500 ft. above low sandhills that cover the coastal strip east to Pohara. Cliffs of limestone extend from Pohara for two miles to Ligar Bay, where they form a rugged coast and provide a useful harbour for the cement-works at Terakohe.

PREVIOUS GEOLOGICAL DESCRIPTIONS

The geology of the Parapara Subdivision was described by Bell (1907), who lists and discusses earlier geological literature and gives much information about the coalfield. Motueka Subdivision adjoins Parapara Subdivision to the south and was later mapped by Henderson, Grange, and

Macpherson; and maps on a scale of one mile to an i[illegible] were published. The structural depression, the northern part of which contains the Takaka coalfield, extends south to Takaka Survey District, part of the Motueka Subdivision. Although marine Tertiary beds are well represented, coal measures are almost absent, and no workable coal has been reported in Takaka Survey District.

STRATIGRAPHY

Bell (1907, p. 49) divided the Tertiary beds into three groups:—

(3) Blue and yellow clays.

(2) Limestone, in places arenaceous or argillaceous.

(1) (*a*) Quartzose conglomerate.

(*b*) Conglomerates, shales with coal-seams, and sandstones.

Finlay and Marwick (1940, p. 120) state that the limestone is not younger than Waitakian and that the overlying marl, the base of Bell's "blue and yellow clays," is of "true" Hutchinsonian age. The following are the ages adopted in this report and the thicknesses of the formations mapped:—

	Ft.
Awamoan-Hutchinson: Mudstone and marl	500+
Waitakian: Limestone	200
Age unknown: Coal measures	(0–2,000)
Unconformity.	
Palæozoic basement: Marble, schist, and granite.	

The mudstone, the uppermost member of the Tertiary sequence preserved, is confined to the deeper parts of the synclines, where erosion has reduced its thickness to a maximum of 500 ft. A stratum of fossiliferous sandy marl separates the mudstone from the underlying limestone. The limestone extends for 200 ft. below the sandy marl and changes little in thickness or composition within the coalfield. It is far more resistant to erosion than the other Tertiary beds, and is exposed as several conspicuous escarpments. The coal measures below the limestone vary considerably in thickness and contain seams of coal which form the economic basis of this report.

Mudstone.—It is convenient to consider the mudstone first, for, although it covers a total area of 4 square miles, it is mostly overlain by recent gravels. It is soft, easily eroded, and never rises far above base level, and outcrops are few. Although deeply weathered and with ill-defined bedding planes, the mudstone is structurally important as it marks the synclines, being the highest bed in the Tertiary sequence. The largest area of mudstone is in the main syncline which defines the centre of the Takaka depression. The syncline extends due north from Rameka Creek to the coast between Waitapu Hill and Motupipi and is covered by an almost continuous sheet of recent gravels, mudstone being exposed only at the south. Both flanks of the syncline are exposed in Rameka Creek, and on the West side a few chains from the Upper Takaka Road the gradual transition of mudstone to sandy marl and then to limestone is clearly shown. The Rameka Creek outcrops were incorrectly mapped by Bell as coal measures, the only mudstone mapped by him within the whole coalfield being part of a narrow strip within a smaller syncline that extends from the Terakohe cement-works near Ligar Bay almost to Kitty Creek.

Limestone.—The limestone, being far more resistant to erosion than either the overlying mudstone or the underlying coal measures, often forms

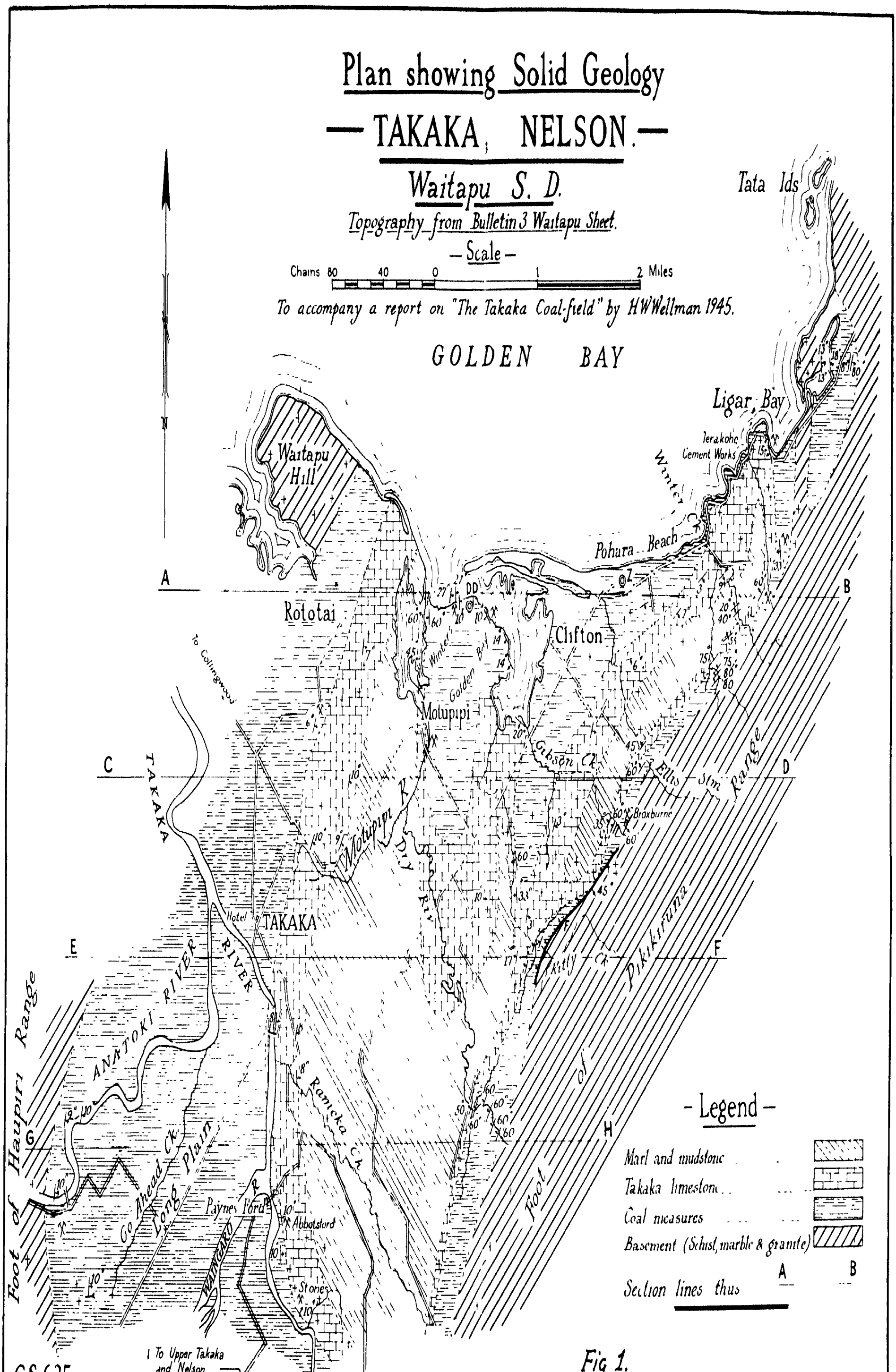
Plan showing Solid Geology
— TAKAKA, NELSON.—
Waitapu S. D.
Topography from Bulletin 3 Waitapu Sheet.
— Scale —
Chains 80 40 0 1 2 Miles
To accompany a report on "The Takaka Coal-field" by HWWellman 1945.
GOLDEN BAY
Tata Ids
Ligar Bay
Tarakohe Cement Works
Waitapu Hill
Pohara Beach
Rototai
Clifton
Motupipi
TAKAKA
Hotel
Payne's Ford
Abbotsford
Stones
To Collingwood
To Upper Takaka and Nelson
Haupiri Range
Pikikiruna Range
Legend
Marl and mudstone
Takaka limestone
Coal measures
Basement (Schist, marble & granite)
Section lines thus
G.S. 635
Fig 1.

Fig. 1.

conspicuous escarpments that enable the structure to be mapped with some certainty. The structure for the whole length of the west side of the coalfield is clearly defined by a gentle east-dipping escarpment which extends on the east side of the Takaka River from half a mile south of Payne's Ford north nearly to Golden Bay. The escarpment is not continuous, but is interrupted by the gravel-filled valleys of lower Rameka Creek and upper Motupipi River. At the south end of the field the band of limestone that forms this escarpment dips gently eastward beneath the mudstone that fills the main syncline, reappearing as the limestone hogback that follows the foot of the Pikikiruna scarp for five miles from Rameka Creek to the coast at Ligar Bay. For the whole of this distance the hogback is a strikingly continuous topographic feature broken only by the narrow gorges of the streams that flow through it from the Pikikiruna Range. Between the limestone and the scarp of the range is a sheltered valley cut in the softer coal measures. Another band of limestone extends from Kitty Creek to the coast at Ligar Bay. It is half a mile north-east of the limestone hogback, sub-parallel to it over most of its length, but connects at both ends to enclose the small synclinal area of mudstone. This limestone band is well exposed in the coastal cliffs that extend from Pohara to Ligar Bay. Another band of limestone branches from the hogback at Kitty Creek. It is not continuously exposed, but outcrops show a gradually increasing westerly dip as it is traced to the north. The three bands of limestone join near Kitty Creek, where, by a fortunate accident of erosion, the mudstone having been evenly stripped from the top of the limestone, every detail of a somewhat complex junction of fold axes is clearly shown. Although the limestone has been so strongly folded that within 3 chains the dip is first to the west at 70° then horizontal and then again to the west at 17°, no faults were seen, the limestone having adjusted itself by the formation of a well-marked conjugate joint system intersecting in the direction of the fold axes. The horizontal part of the above fold represents the termination of the small mudstone-filled syncline described above.

The only other regular band of limestone has already been described by Bell, who states (1907, p. 58): "on the eastern bank of the Motupipi River a band of limestone extends from the river mouth to near the bridge on the Takaka–Clifton Road. It apparently has a steep dip to the west, but this is probably due to the undermining action of the river, the underlying strata lying fairly horizontal." Neither the explanation nor the whole of the facts given by Bell can be accepted, for nearby coal-measure sandstone was found to dip as steeply as the limestone. Moreover, the dip of the limestone is quite regular, decreasing from 60° at the mouth of the river to less than 45° near the bridge. The limestone must be accepted as part of the steep-dipping west limb of a fold analogous to the limestone hogback along the foot of the Pikikiruna Range.

The outcrops of limestone that have been described enable the structure of most of the field to be mapped with some confidence; but the structure of the remaining part, especially that between the lower reaches of Dry River, Motupipi, and Clifton is less certain, for no continuous outcrops occur, but the presence of limestone is deduced from scattered outcrops, sinkholes, and dry stream beds. From this scanty evidence it is inferred that the steep-dipping belt of limestone at Motupipi River extends south along the valley of Dry Creek, then doubles back on the west side of a coal-measure syncline exposed on the coast at Motupipi, and then finally swings to the south again to the steep-dipping band of limestone in Kitty Creek already described.

Coal Measures.—Coal measures are exposed in three parts of the coalfield: on the eastern side as a narrow steep-dipping seven-mile-long belt between the limestone hogback and the Pikikiruna Range; as a flat-dipping belt on the west side of the field from Waingaro River north to Waitapu Hill, and on the south shore of Golden Bay from Motupipi to Pohara.

The steep-dipping belt along the foot of the Pikikiruna scarp provides the best sections; the most complete, at Dry River, showing at least 1,700 ft. of coal measures. Although the beds dip steeply east, there is no more than 3° variation from the average 57° dip, and even this may merely represent depositional irregularities. The strike is equally regular. Outcrops, although not continuous, are sufficient to indicate the general lithology and to suggest the probable thickness of the coal seams. The limestone grades down into a 100 ft. band of quartz sandstone, which overlies the first definite non-marine bed. Below come 3 ft. to 10 ft. beds of alternating sandstone, mudstone, and shale. Twenty seams of coal are distributed throughout the section, but the thickest is only 4 ft. There is a noticeable difference between the upper and lower part of the section. The upper quartz sands are clean and contain little clay, whereas the lower ones are argillaceous and interbedded with thin beds of white clay. Some beds of clay may have economic importance, and an analysis is given by Bell (1907, p. 61). The stratigraphic lowest and most easterly outcrop, quartz and schist conglomerate, is exposed on the south side of the stream not far from marble, which forms the undermass of the scarp. In Kitty Creek, the next creek to the north-east, coal measures are vertical. Although a seam in this stream was mapped by Bell, it was not reobserved. About half a mile farther north-east in Gibson Creek deformation reaches a maximum and the coal measures are locally overturned so that they there dip steeply below the marble undermass. No basal conglomerate was seen, and the contact between the coal measures and undermass may be a reverse fault. Below the marble comes 30 ft. of shale, 4 ft. of coal, 1 ft. of clay, and a further 1 ft. of coal. The 4 ft. seam has been worked, and an attempt was made to mine coal 3 chains downstream where two drives followed stratigraphically higher seams along their strike. The base of the limestone, a chain downstream from the drives, is not overturned and dips north-east at 60°. Deformation continues to rapidly decrease downstream and the top of the limestone dips at 35° only. Deformation also decreases northward along the foot of the scarp, and at the south end of Ligar Bay the dip is but 15°.

On the west side of the field, coal measures crop out at several places close to the footbridge over the Anatoki River, two and a half miles south-west of the township of Takaka. The most northerly outcrop examined is on the north side of the river half a mile downstream from the bridge. A continuous 15 chain section of moderately soft sandstone, mudstone, and shale dips evenly eastward at 10°. Underlying beds on the opposite side of the river immediately below the footbridge show thin seams of coal, which also dip east at 10°. A 9 in. seam has been prospected a few chains south of the bridge and is probably the continuation of one of the seams exposed in the river. Half a mile farther south and near a small tributary of Go Ahead Creek a drive extends west for 5 chains through the base of the coal measures under a gravel veneered terrace. Near the portal, sandstone, which dips east at 10°, is underlain by deformed mudstone and shale. Leached schist is exposed at the end of the drive, but the coal-measures contact is hidden. No coal was seen. The group of outcrops just described at the extreme west part of the coalfield form the base of the coal measures and rest on the undermass at the foot of the Haupiri Range. The middle

of the coal measures are obscured by the gravels that cover the Long Plain between Anatoki and Waingaro rivers; but a thin section of the upper part shows immediately below limestone both at Payne's Ford and a mile north of Takaka. The best section is 7 chains south of Payne's Ford, where limestone overlies 50 ft. of massive sandstone and alternating bands of sandstone, shale, and thin coal. A 3 ft. to 5 ft. seam was worked and is described in Mines reports, but no longer crops out. Coal was also worked north of Takaka, but the workings are overgrown and little can now be seen.

Coal measures are well exposed in coastal cliffs near Motupipi for half a mile on both sides of trig. DD. On the west side the structure is not simple. Near the mouth of Motupipi River the beds dip steeply west parallel to overlying limestone. Where next seen, 20 chains from the river, they are dipping east at 27°. The east dip then regularly decreases until a synclinal axis is reached at trig. DD. West of this axis the beds dip from 10° to 20° south-west. Old workings are indicated by a collapsed drive 3 chains west of the synclinal axis and by traces of opencast workings below high-water mark on the other limb of the fold, 20 chains east of the trig. In the same area, but away from the coast, Bell (1907, p. 56) records that for many years previously coal had been extracted from a pit about a mile south-west of trig. DD near the bridge over the Motupipi River. There are now no outcrops at this place and little indications of old workings. The top of the coal measures crops out at Pohara at the foot of old sea-cliffs near trig. Z and not far below the base of the limestone, 50 ft. of clean quartz sand, shale, and a few inches of coal being exposed. The locality, being readily accessible, is of interest, for the exposed beds are flat and the underlying coal measures have not been prospected.

A probable estimate for the total thickness of the coal measures can be obtained from many of the sections exposed in various parts of the coalfield. Although none of these sections is completely satisfactory, when considered together they leave no doubt that the thickness varies greatly. The thickest reliable section at Dry River shows at least 1,600 ft. of coal measures. A similar but less reliable thickness is given by the low-dipping beds west of Payne's Ford. At the foot of the Pikikiruna Scarp near the head of Winter Creek a steep section shows only 800 ft. Possible faulting reduces the importance of this section, but there can be no doubt about the three sections at Taupo, Hamana, and Parapara, all outside the coalfield, and each seven miles distant, and east, south, and north-east respectively of the mouth of the Takaka River. These are very similar and show the limestone resting almost directly on the undermass, the intervening beds being a few feet of quartz sand and conglomerate. Although there is little doubt about the reality of the variation in thickness of the coal measures, there is insufficient evidence to deduce the thickness over the whole field. It is certain, however, that the variations will be reflected by variations in the thickness of the individual coal-seams, and it will not be safe to assume that the seams will extend laterally for more than a few chains without significant variations.

STRUCTURE

The structure of the coalfield is dominated by the Pikikiruna Scarp, a major tectonic feature which forms its eastern boundary. Although this scarp has hitherto been considered a fault scarp (Bell, 1907, p. 50; Cotton, 1922, p. 187), the evidence is not conclusive, for no large dislocation of Tertiary beds has been proved. The steep dip away from the Pikikiruna Range, well shown by all the beds along the foot of the scarp and used as evidence for faulting by Bell and Cotton, is, in reality, evidence against it,

for it allows the eastward projection of the beds to clear the front of the scarp, and makes it possible that they once extended without a major break at least to the top of the Pikikiruna Range. The face of the scarp may well be the stripped surface of the western limb of the Pikikiruna anticline, steeper but otherwise similar to the surfaces first described by Cotton from other north-west Nelson mountains. Similar steep features have since been

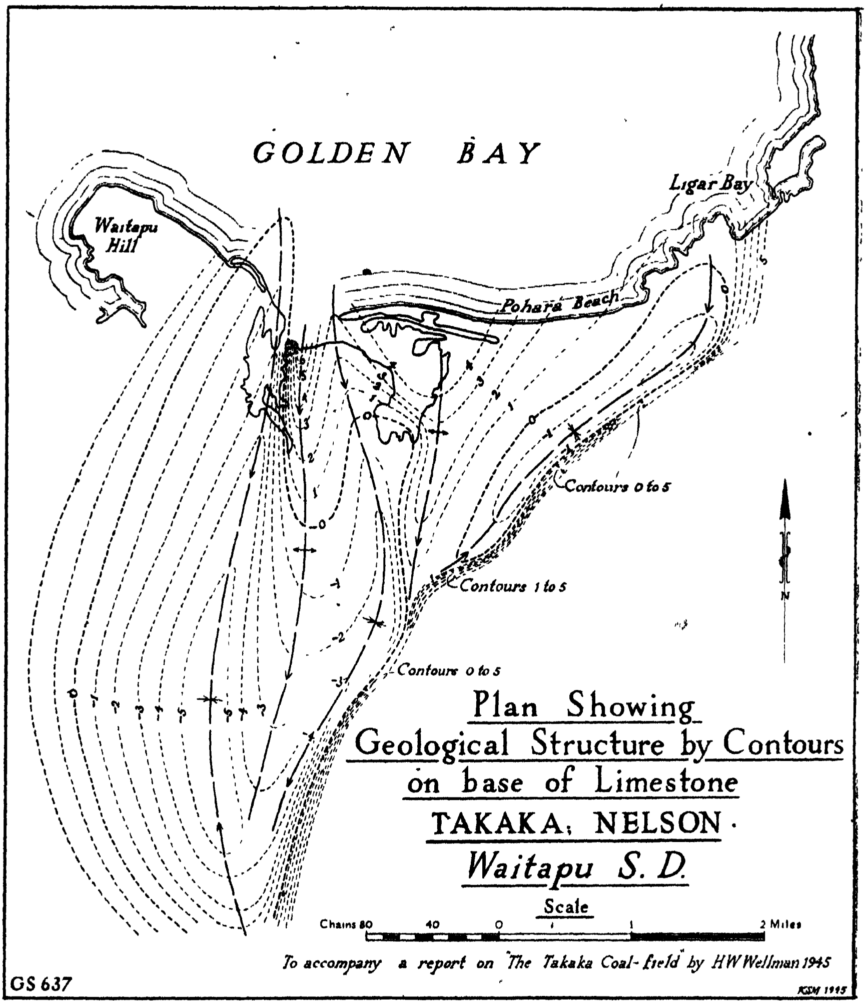

Fig. 2.

described from other parts of New Zealand by Cotton (1942, p. 174) as "monoclinal scarps."

The structure pattern, deduced mostly from the limestone outcrops, is shown by 100 ft. contours drawn at the base of the limestone (Fig. 2). It clearly shows that deformation of the Tertiary beds is not confined to the immediate vicinity of the Pikikiruna Scarp as was suggested by Bell (p. 50), for two anticlines and a complementary syncline plunge south from Golden

Bay, then swing to the south-west almost parallel to the scarp before joining it. Although relative to the Pikikiruna scarp these folds are small, they have amplitudes of more than 500 ft. A third syncline to the west of the other folds defines the deepest part of the coalfield. This, the main syncline, extends due north from the southern part of the field to the Motupipi estuary and the coast, where it is separated from the Pikikiruna scarp by

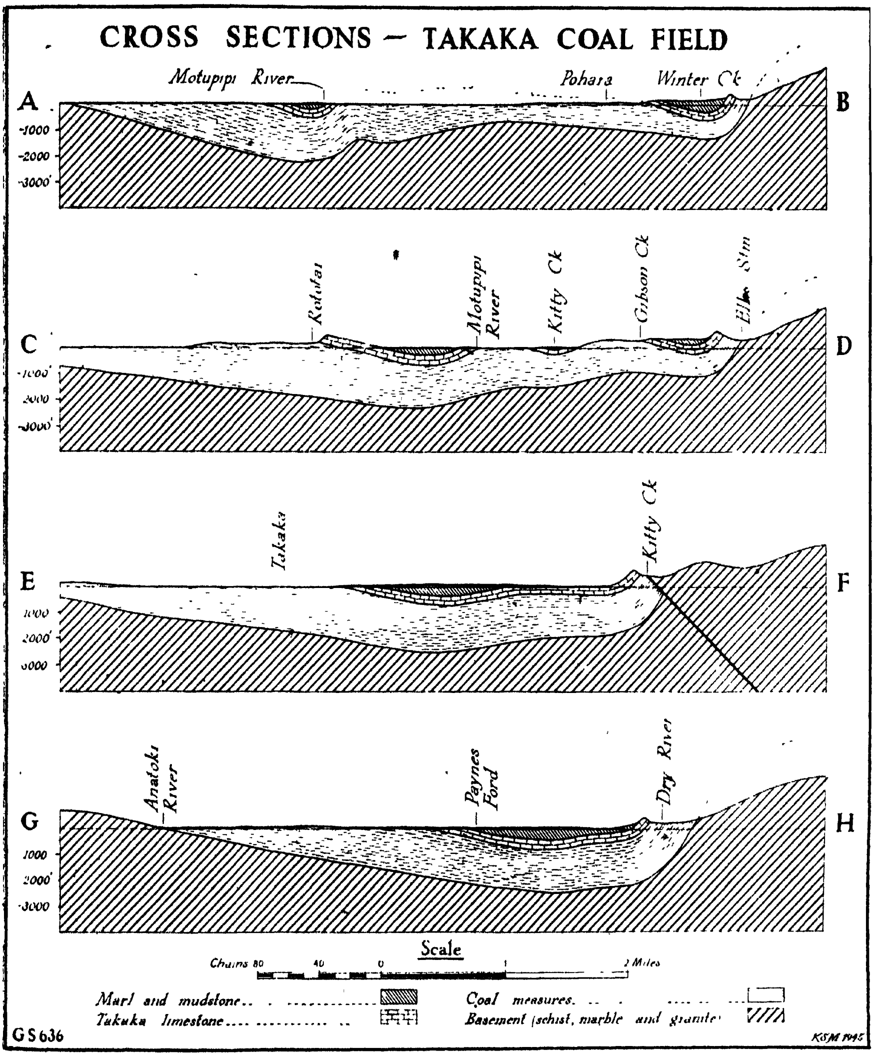

FIG. 3.

the minor folds described above (Fig. 3, cross-sections A–B and C–D). The minor folds are absent in the southern part of the field and the structure is simpler, the Pikikiruna scarp forming the east limb of the main syncline, and the smooth stripped lower slopes of the Haupiri Mountains the western (Fig. 3, G–H). The marked asymmetry shown by the slopes of eastern and western flanks of the field is shared to a lesser extent by the minor central

folds, the east-facing limbs being rarely steeper than 10°, while the west-facing ones may exceed 60°. Although the folds tend to be overturned in the same direction, the pitch of the folds differs, the pitch of the crest of the Pikikiruna Range being to the north, opposite to that of the minor folds.

The structure outlined above is quite different from that shown by Bell's cross-section, which was taken across the northern part of the field between sections A–B and C–D of Fig. 3 of this report. It shows the Takaka depression floored by thin horizontal coal measures, deformed only near the Pikikiruna scarp, and overlain by outliers of limestone. Neither the main syncline, the mudstone, nor the minor folds are shown. Bell consistently underestimated the Tertiary deformation, for he considered (1907, p. 50) that the Tertiary beds " within the Parapara Subdivision are not contorted, though subject to minor and sometimes pronounced irregularities in certain localities." Most of these localities were mapped as faults. Cotton (1922, p. 184–7), when discussing the geomorphology of the region, describes it in terms of blocks separated by faults and appears, like Bell, to have visualized a rigid basement broken by normal faults. The truth is more complex and the basement less rigid than the block hypothesis would have us believe, for deformation is not confined to the main scarps, although it may be better shown there, but extends to the areas still covered by Tertiary sediments, and probably to the stripped anticlinal areas also. It has been shown that there is little, if any, evidence that the Pikikiruna scarp is a fault scarp. It is better considered as the stripped surface of the western limb of an anticline the axis of which is represented by the Pikikiruna Range. The folds within the coalfield then form a complex complementary syncline, and the Haupiri Mountains the next major anticline to the west.

COAL

The first mention of coal was made by Hochstetter (1867, p. 83), who stated that Mr. James Burnett had opened a pit at Motupipi in the early " fifties." The coal was chiefly used by a small steamer trading from Nelson; but, although work was continued for over a year, there is no record of the amount extracted. The next mention of coal being won at Takaka is in the Mines report for 1891, during which year 410 tons were worked opencast and from short drives at Motupipi. The seam was about 5 ft. thick, but contained a stone band of 21 in. In 1893 the coal outcropping beneath the limestone bluffs on the west side of the Takaka River near Payne's Ford was attacked. For many years mining in both areas was most desultory; and between 1895 and 1920 there is a record of a small output for four years only. In 1921 mining began again at Payne's Ford, the pit being known as Stone's, Irvine's, Waikohatu, or Abbotford. Since then a small output was listed each year from the coalfield till 1939, when coal-mining appears to have ceased. A total output of only 4,027 tons is shown on the records; but, as most of the coal was used locally for domestic fuel and the lime-kilns at Motupipi and Payne's Ford, the total is probably greater than that given above. The field has never been important, but the coal measures have not been tested at depth over large areas where the structure is favourable. No new seams were discovered during the survey, and this is not surprising, for the field has been intermittently prospected for nearly a hundred years and all worth-while outcrops mined out. The following

table, which gives the position, thickness, and depth below the limestone of known seams over 2 ft., is based chiefly on Mines reports :—

TABLE GIVING DETAILS OF COAL-SEAMS OVER 2FT. THICK

Locality	Thickness, in Feet.	Depth from Limestone, in Feet.	Authority for Thickness.
Stone's, one mile south of Payne's Ford ..	3–5	50–60	Mines report.
Broxburne, Gibson Creek	5–6	700 (approx.)	Mines report and observed.
Golden Bay Mine, Motupipi, exact locality uncertain	5	400 (approx.)	Mines report.
Winter's, Motupipi, exact locality uncertain	2–3	400 (approx.)	Mines report.
Dry River	3–4	150	Observed.
Dry River	3	520	Observed.
Dry River (largely shale)	6	1,180	Observed.

The table, which makes no pretence to accuracy, shows that the coal-seams are not confined to any particular horizon, but are somewhat more common in the upper than in the lower part of the coal measures.

The analyses given below were made by the Dominion Laboratory and are selected from a number of ill-located ones :—

PROXIMATE ANALYSES

Particulars.	Laboratory Number	Moisture.	Volatiles.	Fixed Carbon.	Ash.	Sulphur.
(1) Motupipi : Upper seam ..	1101/1	14·4	41·9	41·3	2·4	4·89
(2) Motupipi : Lower seam ..	1101/2	13·7	41·0	42·7	2·6	5·66
(3) Kitty Creek	1101/3	14·9	39·5	39 2	6·4	2·21
(4) Irving Mine, Payne's Ford	N/2669	18·6	41·5	33·8	6·1	4·59
(5) Gibson Creek	O/2553	19·4	36·7	33·7	10·2	0·94
(6) Gibson Creek	O/2656	19·0	38·8	31·0	11·2	0·89
(7) Gibson Creek	B/2674	18·6	35·1	38·4	7·9	0·62

The coal is of medium sub-bituminous rank and of a type with about equal parts of volatile matter and fixed carbon and similar to the better-known Kaitangata and Waikato coals, except that the sulphur content is higher. The higher seams at Motupipi and Payne's Ford ((1), (2), and (4)) have a higher sulphur content than the lower seams at Kitty Creek and Dry River ((3), (5), (6), and (7)), and it is not improbable that the sulphur content varies with the stratigraphic position, but insufficient analyses have been done to make this certain. The moisture content varies considerably, but shows no direct relationship to the deformation the beds have suffered, the coal from the steeply dipping beds along the foot of the Pikikiruna Range ((3), (5), (6), and (7)) having slightly more moisture than the coal from the flat dipping beds near Payne's Ford and Motupipi ((1), (2), and (4)). The variation in the moisture content may be due in part to loss of water after sampling and before analysis, for all the coals lose water on exposure to dry air. All are non-coking.

When discussing the coal prospects it is best to consider as separate "blocks" areas that differ considerably in amount of deformation and degree of exposure. The best exposed block is the strip of coal measures between the limestone hogback and the Pikikiruna Range. Although coal

has been won from shallow drives at various places over the whole length of this block, it is of little economic importance, being so steep that it cannot be worked economically at depth.

The next best exposed block is at Motupipi, where it would be very surprising if any thick outcrops remain undiscovered, the upper part of the coal measures having been prospected and worked for nearly a hundred years. The lower parts of the coal measures are not exposed, but the structure is not as favourable as elsewhere in the field.

The largest and least deformed block is on the west side of the main syncline both east and west of the limestone escarpment. Only the upper few feet and the lowest hundred feet or so of the coal measures outcrop and there is a fair chance of workable coal being found in the middle part, which has never been examined. A smaller equally regular untested block extends from Clifton to Ligar Bay between the small mudstone-filled syncline and the coast. These two blocks can best be prospected by drilling, the best drill sites being close under the limestone on the up-dip side where the whole of the coal measures underlies, and no effort will be wasted drilling into the non-productive marine beds.

CONCLUSION

The Takaka coalfield does not compare favourably with other New Zealand coalfields; but, as these other fields are progressively exhausted, Takaka coal will become relatively more important. The area has the advantages of good access and gentle uniform low dips over two comparatively untested areas. The field will not be proved or disproved by a few drill holes, for the seams are likely to be very irregular in thickness.

REFERENCES

BELL, J. M.; WEBB, E. J. H.; and CLARKE, E. DE C. (1907): The Geology of the Parapara Subdivision. *N.Z.G.S. Bull.*, *3*.

COTTON, C. A. (1922): "Geomorphology of New Zealand," Part 1, Wellington.

——— (1942): "Geomorphology," Wellington.

HOCHSTETTER, F. VON. (1867): "New Zealand: its Physical Geography, Geology, and Natural History."

FINLAY, H. J., and MARWICK, J. (1940): The Divisions of the Upper Cretaceous and Tertiary in New Zealand. *Trans. Roy. Soc. N.Z.*, *70*, 77–135.

GEOLOGY OF THE KARAPIRO DISTRICT, CAMBRIDGE

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Summary

The geology of the Karapiro Dam site and surrounding district is described in detail, and related to that of the surrounding region.

The first part of the paper deals with the topography, physiography, and stratigraphy. A basement of Jurassic greywackes and argillites is covered at lower levels by a set of Pliocene to Recent deposits comprising silts, sands, gravels, and volcanic breccias and tuffs. The young deposits are divided into four main mappable units, two of which have been allotted series names.

An earlier depression across the basement rocks was filled with younger sediments; and the Waikato River was superimposed on the basement rocks near the margin during a late period. Since then the river has carved a gorge in the greywacke, and in this gorge is the site of the dam.

The second part of the paper deals with the engineering aspects of the geology of the dam and power-house sites and the diversion tunnel. In addition the possibilities of leakage along the earlier depression adjacent to the present course of the river, through younger and fairly permeable beds, is discussed.

INTRODUCTION

IN connection with hydro-electric development of the Waikato River, the writer has during the last few years carried out geological investigations along various stretches of its course, and, in July, 1941, spent two weeks at the site of Karapiro Dam, which is at present under construction. Before this visit a tentative site had been selected for the dam, geophysical investigations had been carried out by Mr. Modriniak, an extensive boring programme had been carried out, excavation of the right bank was under way, and the diversion tunnel was mostly completed, so that good outcrops were visible. The writer submitted to the Works Department a report on the geological investigation of the dam site and surrounding area.

Since then two visits have been made in August and December, 1944, to inspect more recent investigations and bore results. This paper includes the information gathered during the three visits.

Karapiro is a small district five miles south-east from Cambridge along the State highway towards Rotorua. At this point the side road to the dam branches south, and the site is three-quarters of a mile from the turn-off. It was necessary to examine the surrounding area, and this paper accordingly deals with the geology of approximately eight square miles of country through which pass the Waikato River and the State highway.

Two plans accompany the report. Figure 1 shows the geology of the entire area mapped, and Fig. 2 the detailed visible geology of the dam site itself at the time of the first visit. The blank spaces in Fig. 2 represent areas occupied by loose spoil removed during excavation.

PREVIOUS WORK

The area has not previously been mapped. Lying as it does between the middle Waikato or Hamilton basin and the Maungatautari gorge, its geological history has frequently been inferred in papers dealing with those

two features. The following, then, should be regarded rather as a summary of previous geological literature dealing with the adjoining regions, but with specific bearing on Karapiro. On this other work the present correlations are based.

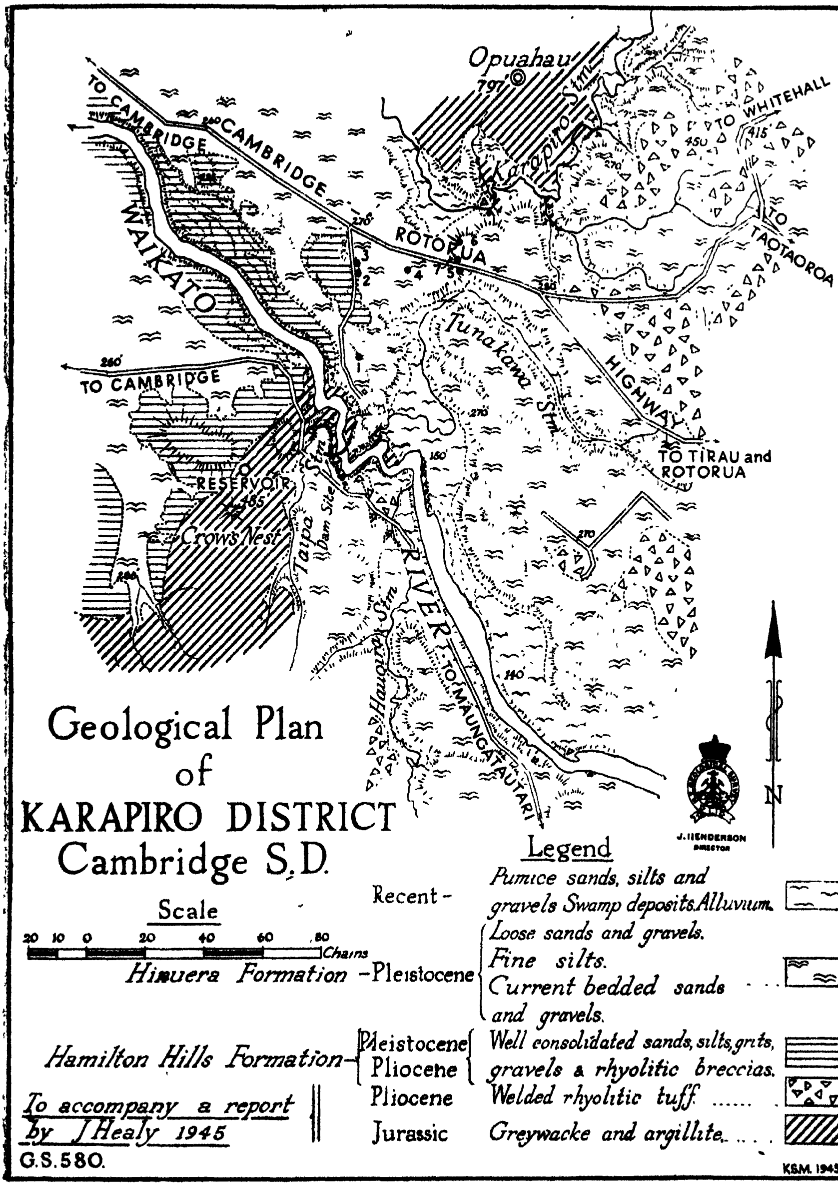

FIG. 1.

Regional work is based on the earliest report, which was made by Hochstetter (1867). He named the Middle Waikato basin, and considered it to have been an arm of the sea prior to the last elevation of the land.

In a comprehensive discussion of the physiography of Waikato River, Cussen (1889) advanced the now generally held hypothesis that during the past it had frequently changed its course, and was the first to suggest that formerly it flowed to Hauraki Gulf through Hinuera valley, some six or seven miles east of Karapiro. He considered that the sands and gravels of the Waikato fan above Maungatautari gorge were laid down in a lake, which later extended through the middle Waikato basin when the river changed its course, and that both lakes were subsequently drained. To account for these changes he postulated movements of the land relative to sea-level, accompanied by local oscillations. He further developed these ideas in a later paper (1894).

Henderson (1918) described the sediments and physiography of the Waikato valley above Maungatautari gorge in detail, and elaborated on the changes of course of the river. He visualized them as being brought about by meandering and spillover during a period of alluviation caused by depression of the land. Murray (1919) considered the change of direction of flow of the river at Hinuera to be due to tilting during the rise of Coromandel Range.

In the most complete discussion to date on the regional geology, Henderson and Grange (1926) outlined a suggested sequence of movements of the land relative to sea-level, and defined the Pleistocene with reference to them. The area they described extends from the west coast to the western boundary of Cambridge township, but the Pleistocene and Recent deposits continue into Karapiro district. The history of the Waikato was also further developed.

Mead (1938) has described a contiguous area to the north; and other recent writers (Taylor, 1935; Taylor and Grange, 1939) have outlined the regional geology in papers dealing with water-supplies and soils of adjacent regions.

TOPOGRAPHY AND PHYSIOGRAPHY

The dominant feature of the district is a plain extending north-west from one to two miles wide and between 250 ft. and 280 ft. above sea-level, with a gentle slope downwards towards the north-west. Through it, incised to a depth of 200 ft., flows the Waikato River: on the plain runs the State highway. Below the mouth of Tunakawa Stream the Waikato flows in a narrow canyon, but above that point the valley widens and there is a well-defined terrace 70 ft. above river-level and 130 ft. below the level of the plain. To the north-west the plain expands into the Hamilton or middle Waikato basin, but to the south-east it narrows and disappears except for a few remnants high up on the flanks of the Maungatautari gorge.

Above the plain rise a few low hills, but beyond it north and south rise fairly steep greywacke ridges. The dam site is located on the north toe of the southern ridge, which rises south of the river to a height of 485 ft. above sea-level at the Crow's Nest, and beyond that to 1,274 ft. at Pukekura. The Waikato follows a devious course for half a mile, where it flows through the greywacke gorge cut in the partly buried north end of the ridge. A mile north of the river the northern greywacke range rises, more or less in continuation of the line of the southern ridge, to a height of 797 ft. above sea-level at Opuahau, a mile from the highway. East of this range are lower hills of rhyolitic tuff.

Into the Waikato, a short distance above the dam site, flow Hauoira Stream from the south and Tunakawa Stream from the east. The latter, after emerging from the hills of rhyiolitic tuff, flows north-west parallel

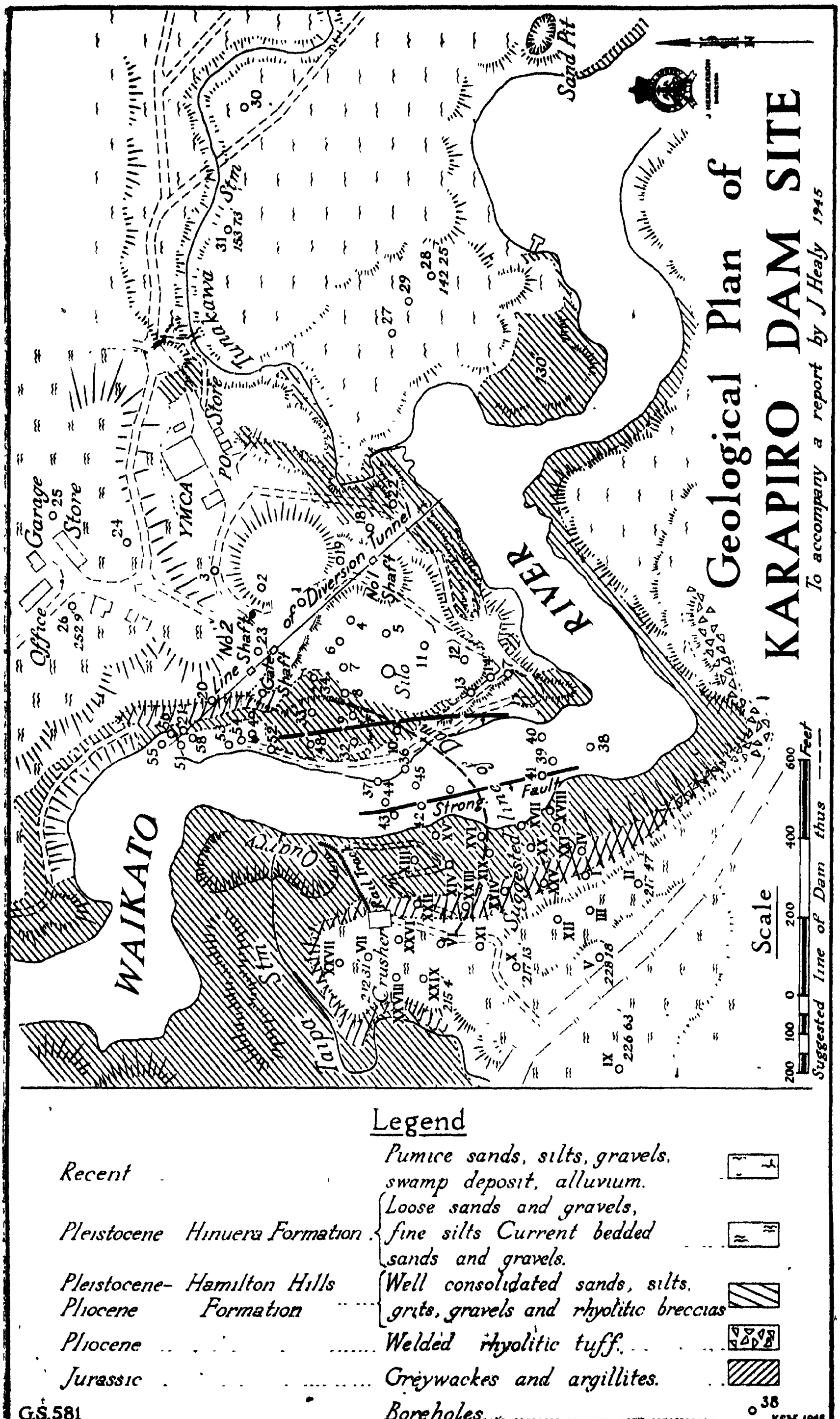
Geological Plan of
KARAPIRO DAM SITE
To accompany a report by J Healy 1945
Scale
Feet
200 100 0 200 400 600
Suggested line of Dam thus
WAIKATO
RIVER
Office
Garage
Store
YMCA
PO
Store
Sand Pit
Silo
Crusher
Rail Track
Line of Diversion Tunnel
Gate Shaft
No 2 Line Shaft
No 1 Shaft
Strong Fault
Suggested line of Dam
Taipa Stm
Tunakawa Stm
Legend
Recent ... Pumice sands, silts, gravels, swamp deposit, alluvium.
Pleistocene Hinuera Formation ... Loose sands and gravels, fine silts Current bedded sands and gravels.
Pleistocene-Pliocene Hamilton Hills Formation ... Well consolidated sands, silts, grits, gravels and rhyolitic breccias
Pliocene ... Welded rhyolitic tuff
Jurassic ... Greywackes and argillites.
Boreholes ... 38
G.S.581
K&M 1945

FIG. 2.

to the Waikato for over a mile, trenched deeply in the plain, then turns south-west to the river. The Karapiro drains south along the contact between the northern greywacke range and the rhyolitic area, turns west round the toe of the range, then flows north-west and joins the Waikato at Cambridge, five miles away.

The greywacke ranges form the sole remnants of a late Pliocene topography, though no doubt modified to a certain extent since then. The depressions on the east side at any rate were, near the close of the Pliocene, filled with a sheet of welded rhyolitic tuff, then the present depression through which the Waikato flows was carved by erosion and probably modified by faulting.

After this followed a series of movements of the land relative to sea-level, causing alternating periods of accumulation and degradation of sediments. The low hills projecting above the plain and bordering the eastern margin of the Pukekura ridge are composed of the sedimentary and volcanic beds that were laid down during the first subsidence. They filled the Hamilton basin to a great depth, but were well eroded in turn when the land again rose. The Waikato at this stage flowed to the Hauraki Gulf by way of the Hinuera valley, but, during the next lowering of the land, aggraded rapidly till it spilled over and followed the course of the present Maungatautari gorge into the Hamilton basin. At Karapiro the river flowed north of its present course nearer the northern greywacke range. Aggradation immediately commenced in this part, and an immense and extensive fan was laid down throughout the entire Hamilton basin and beyond, during which time changes of course of the river were frequent. The plain described above is the upper surface of this fan. The sediments composing it are loose, current-bedded sands and gravels. Once again elevation of the land caused the river to become entrenched along its course, and caused certain anomalies. Instead of taking its former course it now cut down through the thin cover of loose sediments along the course to which it had wandered on the surface of the fan, into the buried greywacke toe of the ridge to the south. This has given rise to the greywacke gorge there, in which is the dam site. Up-stream is a wide valley cut in the loose sediments of the fan, but down-stream the canyon mentioned previously is cut in the more consolidated earlier sediments.

The lower terrace up-stream from the dam marks the final alluviation of the Waikato, this time apparently caused simply by overloading with light sediment from the central pumice eruptions of Recent age. This phase also produced changes in the drainage. The Waikato itself, when it cut down to its present level again, took a different course within the wide valley cut in the earlier fan. Just up-stream from the mouth of the Tunakawa it now cuts through a short greywacke barrier, whereas it formerly swung farther north-east in the direction of the Tunakawa. That stream has consequently been lengthened. A mile up-stream the Waikato has uncovered in its bed stumps of a forest that was buried by the pumice aggradation, and that presumably covered the flats adjoining the former course of the river. Hauoira Stream was deflected down-stream and became superposed on welded rhyolitic tuff into which it has cut a narrow, deep channel along portion of its lower course. The lower Tunakawa has been extended owing to the change of course of the Waikato. There is reason to believe that the Waikato itself is now flowing 20 ft. or so above its level prior to the pumice aggradation.

As the Waikato cut down through the greywacke it gradually adjusted its course to the internal structures of those rocks.

STRATIGRAPHY

Summary

The Karapiro district lies on the northern fringe of the central volcanic plateau of the North Island, where, during the Pliocene and Pleistocene, extensive deposits of volcanic material accumulated from a series of large scale eruptions chiefly rhyolitic in character. Over many hundreds of square miles the underlying sedimentary rocks are completely masked, but in the marginal areas they project through the volcanics or have become exposed by erosion.

The rocks of the Karapiro district fall, therefore, into two main groups—an older, sedimentary basement, and a younger covering of volcanic tuffs, ash-beds, and transported material. Greywackes and argillites of Jurassic age form ranges projecting above the younger cover from Morrinsville in the north to fifteen miles west of the southern end of Lake Taupo in the south, and a similar parallel series of ranges forming the western upland of the Huntly-Kawhia region to the west (Henderson and Grange, 1926). They trend north, parallel to the strike of the component rocks. At Karapiro the Waikato breaches the first range from east to west.

The greywacke terrain is the unburied remnant of a Pliocene land surface, which had attained moderate relief, produced, probably, by faulting movements modified by erosion. There is no sign of any earlier Tertiary covering.

The younger covering beds consist of volcanic deposits varying from welded tuff to loose ash, and fluviatile sands, gravels, breccias, and silts. They include deposits of ages from Pliocene to Recent, and have been divided into four mappable units.

The geological formations present are summarized in the following table :—

Age.	Formation.	Deposits.	Thickness.
Recent ..	..	Loose pumice sands and gravels, containing fragments of charred wood	100 ft
Pleistocene	Hinuera formation	Reddish-brown volcanic ash ..	3–4 ft.
		Loosely consolidated sands and gravels. Sands and fine silts . . Current-bedded, coarse sands and gravels	At least 285 ft.
	Hamilton Ash ..	Reddish-brown volcanic ash .	3 ft.
Pleistocene–Pliocene	Hamilton Hills formation	Poorly consolidated rhyolitic breccias, sands, silts, and gravels	At least 370 ft.
Pliocene ..	..	Welded rhyolite tuff	?
Jurassic .	..	Greywackes and argillites	?

Jurassic Beds

The rocks of this series are alternating bands of greywacke and argillite, the former massive and the latter well stratified. The average strike is a few degrees west of north, and the dip at least 60° west. The trend of the Pukekura ridge to the south and the Opuahau ridge to the north is parallel to the strike, which controls their structure.

The best exposures in the district are to be seen where the Waikato cuts through the northern end of the Pukekura ridge. Here greywacke and argillite are exposed for 40 chains up-stream and 30 chains down-stream from the dam, which is being built on a foundation of these rocks. They are intersected by numerous faults, the chief set being strike faults mainly developed in the argillite members along bedding planes. They would be induced in the rocks at the time they were so strongly folded, and any later movements would tend to be taken up along these weak planes.

Other faults are developed, but to a lesser extent. There is a set of which the members strike north-west and dip mostly south-west. Another set strikes east to south-east and dips north to north-east usually at low angles. Other faults strike north-east and dip north-west. Where Taipa Stream enters the Waikato it follows a small weak zone trending east.

Joints are prominent, especially in the massive greywackes, which are intersected by a closely spaced system of joints typical of such rocks in other districts. Locally particular sets of joints that parallel the main fault planes are dominant.

Such closely spaced joints greatly assist weathering, which has preceeded deep below the old Pliocene land surface. On the surface are stiff brown clays, which pass down through broken rubbly rock with a decreasing amount of weathering to the fresh rock. In the zone above the fresh rock, spheroidal weathering has produced rounded cores of unweathered rock in a brown, weathered matrix. The unweathered rocks vary from hard, siliceous greywacke to less indurated argillite.

The fresh rock has been exposed along the banks of the river and for some distance upwards; but at its highest levels in the gorge the rock is well weathered and has had to be removed to lay bare a suitable foundation for the dam. Below river-level, fresh rock only is found, any weaknesses existing there being due to crushing of the rocks and not to weathering.

At the time of the writer's first visit a strong strike fault was found near the site of Bore 10, and its outcrop could be followed for some distance north along the exposed rock. Within a zone of 10 ft. are three well-defined bands of fault pug and breccia from 6 in. to 12 in. thick. Near Bore 33 another outcrop of a fault zone 2 ft. thick was found 80 ft. east of the last. Numerous minor parallel faults were found on the right bank of the river west of the entrance to the diversion tunnel. It was thought at the time that more would be found in the bed of the river when it became exposed, and this has been the case.

During the last visit maximum excavation was completed, and the cut-off wall at the base of the dam was under construction Excavations here revealed a former huge pot-hole extending to 18 ft. below sea-level. The centre of the pot-hole coincided with the outcrop of a strong fault with a well-developed crush zone 6 ft. to 8 ft. thick, in which the rock had been finely shattered, without being completely pugged. East of this crush zone is 15 ft. of argillite with quartzitic bands in which probably 50 per cent. of the material is finely crushed in bands. Between this fault and the strong one described in the previous paragraph the strike of the argillite swings from normal to north-east, suggesting that both are faults of fair magnitude. Elsewhere the strikes are fairly normal.

A section across the dam site (Fig. 3) shows from the extreme end of the cut on the left or west bank massive greywacke passing into argillite and then again into greywacke, which forms the former left bank. This is separated by a fault from the argillite of the river-bed that is crossed by the two strong faults described above. On the right bank this passes again to greywacke. Thus the river in this portion follows a band of argillite, its banks are in part fault-defined, and the deepest portion coincides with the strongest fault.

A fossil found in these old rocks at the dam site was forwarded to Dr. J. Marwick, who identified it as *Buchia malayomaorica* (G.S. 2905), and upon this evidence the beds have been assigned to the Upper Jurassic. This accords with the finding of Jurassic fossils in similar rocks near Morrinsville (Bartrum, 1937), at a locality in direct continuation of the strike of the Karapiro rocks.

Welded Rhyolitic Tuffs

Welded rhyolitic tuff forms the hills rising above the level of the Waikato fan east of the greywacke ranges. It also crops out in a small gorge in Karapiro Stream, where it is faulted against greywacke, and in the lower course of Hauoira Stream, whence it extends north-west for 20 chains to the banks of the Waikato. The hills to the north-east extend into the contiguous area that has been described by Mead (1938).

Where exposed, the tuff shows the usual vertical jointing and cliffed development characteristic of these rocks. Inclusions of pumiceous rhyolite up to several inches in diameter are numerous. The rocks of this sheet have been described by Mead, and are similar to those referred to as "ignimbrite" by Marshall (1935) and composing the greater part of the central volcanic plateau.

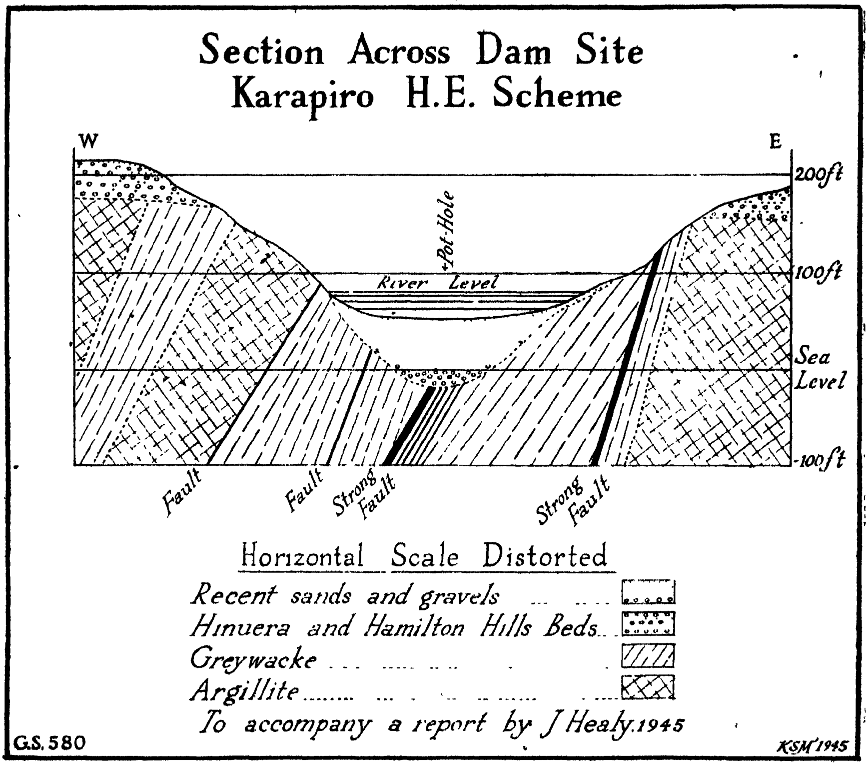

FIG. 3.

The sheet of welded tuff is said by Mead to fill a former basin east of the greywacke ranges of this area. No contacts with the underlying greywacke are visible except one, half a mile east of the Karapiro turn-off in a small gorge of Karapiro Stream, where the contact is a plane striking north-west and dipping at 52° south-west and is apparently a fault. Downstream from the Hauoira the tuff crops out along the bank of the Waikato to within 10 chains of the dam, where its contact with beds of the Hamilton Hills Formation outcropping at the same level down-stream is obscured, but it appears that the tuff was eroded before those beds were laid down. There are no indications that the latter beds have been involved in faulting, but the tuff seems to have been emplaced, faulted, and then eroded before deposition of the Hamilton Hills beds in the Karapiro area.

No outcrops of welded tuff were found west of the greywacke gap at Karapiro, but the writer has seen outcrops west of the greywacke range several miles to the south-west. If the faulting associated with the Karapiro gap was confined to the period following the emplacement of the tuff, the greywacke may have originally constituted a barrier beyond which the tuff did not extend. If it did pass through to the west, any remnants still existing are buried beneath the later sediments.

The rhyolite tuff is classed along with the other deposits of similar type of the central regions as belonging to the outpourings of volcanic materials that accompanied the eruptions of the Pliocene.

Hamilton Hills Formation

Beds of this formation form low hills skirting the western margin of the Pukekura greywacke ridge and projecting above the level of the alluvial plain north-west of the dam site. They are well exposed in the gorge down-stream from the dam and in the recent excavations at the site, and were also encountered at a depth of 285 ft. in Bore 5 (Fig. 1) below the level of the State highway a quarter of a mile south-east of the Karapiro turn-off.

The best exposure visible at the time of the writer's first visit was on the left bank of the Waikato just over a mile down-stream from the dam site, where a small track has been cut down the steep wall of the bank. The section from the top is as follows :—

30 ft. of light pumice sands and silts.
2 ft. of light-grey clay.
5 ft. of brown sandstone.
5 ft. of light-brown sandy clay.
30 ft. of alternating sands, silts, and grits.
15 ft. of tuffaceous sandstone.
2 ft. of well-cemented gravel, with pebbles of greywacke, and rhyolite up to 1½ in. in diameter.
2 ft. of well-consolidated, fine, pumice gravel.
30 ft. of well-consolidated grits with greywacke gravels, pebbles up to 2 in. diameter.
Below, sands and grits constitute the lowest visible bed, outcropping to near river-level, until obscured by slipped material.

Later excavations at the dam site have exposed these beds well. The following section is shown on the right bank :—

Sands and gravels of the Hinuera beds, lying unconformably on well-bedded sands and silts, unconformable on beds below.
Soft, grey, rhyolitic breccia containing carbonaceous fragments, and showing a small amount of banding at the base, unconformable on
Similar material, but showing a certain degree of sorting towards the base, lying on
Greywacke floor, with extremely uneven surface with pockets of coarse, well-rounded greywacke gravels.

A similar but fuller section is exposed in the excavation on the left bank as follows :—

Sands and gravels of the Hinuera or younger beds, unconformable on
Fine, white and brown silts.
Fine, pumice breccia, containing no carbonaceous material.
6 in. to 12 in. of finely banded, oxidized material, probably a thin volcanic ash.
Rhyolitic breccia, containing carbonaceous material. Contains a carbonized log, 3 ft. in length and 5 in. in diameter. Less compacted towards the top.
Finely banded pumice ash-bed. Rests unconformably and with oxidized contact on
Pumiceous breccia, showing bedding and sorting towards the base.
A coarse, greywacke gravel with pebbles up to 6 in. diameter forms a pocket resting on an irregular surface of weathered greywacke.

The similarity and identity of the lower sets of beds on each side of the river are obvious. In the section on the left bank the ash-bed at the base of the upper rhyolitic breccia has been described separately, but it is merely the basal phase of the bed above, which is believed to be a subaerial deposit. The wavy banding of the basal bed is parallel to the underlying surface, and passes gradually into the structureless mass of the upper portion which, with its numerous inclusions of carbonized material, closely resembles the Recent subaerial pumice ash of the Taupo region. Breccia crops out in the Karapiro road-cutting 10 chains from the highway turn-off, and again in a road-cutting 25 chains north-west from the dam site. The underlying breccia of the sections above was probably deposited subaqueously, for it shows sorting.

The holes shown in Fig. 1 were drilled by the Department of Scientific and Industrial Research at the end of 1944. The writer inspected the samples from Nos. 3, 5, 6, and 7. The following is the log of drill hole No. 1 :—

0 ft. to 95 ft. :	Sand and loose gravels.
95 ft. to 100 ft..	Hard band green tuff.
100 ft. to 110 ft. :	Sand.
110 ft. to 185 ft. :	Sand and coarse gravels.

The upper layer of sand and loose gravels is probably Hinuera material. The Hamilton Ash may be represented by the hard green band, which is not oxidized at depth, but this is doubtful, as it is unlikely that it would be classed as "hard." The remaining 85 ft. of sediments belong to the Hamilton Hills formation and resemble the beds described from the down-stream section on the left bank of the Waikato.

Nos. 2 and 3 were drilled through the Hamilton Hills beds a few chains apart and have similar logs. The samples taken were wash drillings only, so do not give a true representation of the beds encountered. The following is the log of No. 3 hole :—

0 ft. to 15 ft. : Fine, pumiceous material.
15 ft. to 75 ft. : Grey-white pumiceous material, fragments of pumice up to $\frac{3}{4}$ in. in diameter. Probably rhyolitic subaerial ash, and same bed as outcrops in road cutting nearby.
75 ft. to 105 ft. : Similar to the above without larger pumice fragments, but containing a large amount of clear volcanic glass as fragments up to $\frac{1}{16}$ in. in diameter.
105 ft. to 135 ft. : Clay-like material containing gritty fragments of pumice, rhyolite, and greywacke up to $\frac{1}{4}$ in. in diameter.
135 ft. to 155 ft. : Similar to above with less clay, but fragments of volcanic glass in addition.
155 ft. to 175 ft. : Similar, but finer in grade.
175 ft. to 215 ft. : Fine, angular gravels, with pebbles of greywacke, rhyolite, and pumice up to $\frac{1}{2}$ in. in diameter.
215 ft. to 225 ft. : Quartz sand and grit, containing fragments of pumice, rhyolite, and greywacke, from $\frac{1}{8}$ in. to $\frac{1}{4}$ in. in diameter.
225 ft. to 285 ft. : Dark-grey sand, containing gritty fragments similar to those in the bed above.

These sediments also are similar to those of the left bank of the Waikato down-stream from the dam. No. 5 passed through 285 ft. of Hinuera sediments into pumice breccia of the Hamilton Hills formation, resembling that of the subaerial deposit. It is thus possible that the subaerial breccia is unconformable on the fluviatile beds of the Hamilton Hills formation, and is actually a younger deposit. In this case the breccia met at 285 ft. from the surface in No. 5 corresponds with that encountered near the surface in Nos. 2 and 3, as they did not encounter a similar deposit at a depth comparable with that of the former.

However, they barely reached a sufficient depth to prove the possible lateral extension of the breccia encountered 285 ft. below surface level in No. 5 at the same depth.

Hole 5 continued to a depth of 325 ft. from the surface without passing through the breccia—that is to say, to 58 ft. below sea-level. Taking into account the level to which the beds of the Hamilton Hills formation attain in the low hills adjacent to the road near Nos. 2 and 3, it can be seen that they are at least 370 ft. thick at Karapiro.

Henderson and Grange (1926) have described similar beds in the Hamilton region. They extend throughout the Hamilton basin and beyond, and are contiguous with those at Karapiro. They occur typically as low, rolling hills projecting above the surface of the Waikato fan, and it has been usual for soil and geological investigators to refer to them as the "Hamilton Hills" beds, but the name has not previously occurred in publications. The above authors (*op. cit.*) classed these beds with the similar sediments of the Walton beds of the Piako region (Henderson, 1913). The writer has adopted the name "Hamilton Hills formation" for the beds described above, and suggests that this be used for these beds in the Hamilton basin and adjacent areas, and that the name "Walton beds" be retained for the similar beds of the Thames-Matamata depression.

The Walton beds were classed as newer Pliocene and Pleistocene (Henderson, 1913), and their equivalents of the Hamilton basin as Pleistocene (Henderson and Grange, 1926). Since then other writers have referred them to the Pliocene (Taylor, 1935; Taylor and Grange, 1939). Henderson and Grange (1926) postulated depression of the land to 1,000 ft. below present sea-level in the early Pleistocene, during which the Hamilton Hills beds were laid down. Lately Dr. Henderson has informed the present writer that he considers the Hamilton Hills beds to be fluviatile deposits resulting from the erosion of the rhyolitic sheets, and that in the marginal areas the welded tuffs will be found to interfinger with the sediments. He thus places them as contemporaneous with the rhyolite tuffs, and in the Pliocene, which he concludes to have ended with the uplift which initiated the erosion of the Hamilton Hills beds. It is chiefly on these opinions that the later writers above placed the Hamilton Hills beds in the Pliocene instead of in the Pleistocene as formerly.

The evidence for establishing the relation of the Hamilton Hills beds to the extensive sheets of welded rhyolite tuff is by no means complete. Henderson and Grange (1926, p. 61) mention a well-consolidated subaerial tuff underlying subaqueous rhyolitic breccia, but the underlying beds were not exposed. Taylor (1935, p. 19) also mentions subaerial rhyolite tuff, but does not state whether it was welded or not. The writer has described subaerial tuff that has been mapped with the Hamilton Hills beds, but it was pointed out that it may be younger. In the river-bank section downstream from the dam there is a tuffaceous bed, but nothing resembling the welded tuff of the "ignimbrite" type. The evidence at Karapiro is that the tuff of the latter type underwent faulting and erosion before the sedimentary beds of the Hamilton Hills formation were laid down.

It would be reasonable to expect that if erosion of the rhyolites commenced from the earliest period of eruption it would likely be continued during the following eruptions and after they had ceased, provided that elevation of the land was sufficient to permit erosion, so that the Hamilton Hills beds most probably represent the product of erosion during and after the period

of maximum eruption. Grange (1937) has shown that eruptions of a rhyolitic character have continued from the Pliocene to the Recent; but it is considered that the extensive eruptions of the "ignimbrite" type of welded rhyolite tuff occurred during the earlier and most intensive volcanism, which is usually placed in the Pliocene. At Karapiro, tuff of that type is older than the Hamilton Hills beds. The main difficulty is to define the end of the Pliocene and the commencement of the Pleistocene, a problem requiring investigation.

Grange (*op. cit.*) has described beds that the writer considers are probable correlatives of the Hamilton Hills beds, and classed them as Pliocene-Pleistocene. They are highly unconformable to the rhyolite tuffs, in the Rotorua-Taupo region. The Hamilton Hills beds at Karapiro are therefore placed tentatively as Pliocene-Pleistocene.

Hamilton Ash Shower

Overlying the Hamilton Hills beds on the low, rolling hills between the main road and the Waikato is a reddish-brown loamy material representing a volcanic ash that was spread from an eruption after the Hamilton Hills beds had been uplifted and eroded into moderate relief. It also covers other country rising above the level of the Hinuera fan. This bed has been called the Hamilton Shower (Grange and Taylor, 1931, 1939), and it is regarded as being andesitic.

A similar, but more sandy, bed caps the Hinuera fan surface near the Public Works Department office at Karapiro. Taylor and Grange (1939) consider that in places the Hamilton Shower was partly washed from the surrounding hills on to the beds of the Waikato fan, giving a brown loam; but this outcrop is beyond the area they mapped, and younger showers are known to exist to the east, so without laboratory examination of the material of which it is composed it is impossible to say whether it is a true ash or water transported.

The Hamilton Shower extends underground following the contact of the Hamilton Hills beds with the overlying Hinuera fan deposit.

Hinuera Formation

During the period of depression following the uplift and erosion of the Hamilton Hills beds the Waikato transported and laid down large quantities of rhyolitic material from the central regions. This was deposited as coarse, current-bedded sands and gravels, showing a fair degree of sorting. At this time numerous changes of course of the river took place. Cussen (1889, 1894) noted that it formerly flowed through the present Hinuera valley towards Matamata and Hauraki Gulf, but that it turned and flowed through Maungatautari Gorge and Karapiro to the Hamilton basin. Henderson (1918) later developed this thesis, and described the sediments above Maungatautari Gorge. He considered that aggradation continued in the Hinuera valley till the river spilled over into Maungatautari Gorge. As the level of accumulation of the sediments is the same in each direction at the point of change of flow it is likely that during the closing stages of alluviation the river flowed in alternate directions.

Into the Hamilton basin the Waikato built an extensive fan after it changed course. At Karapiro the upper surface of the fan reaches a maximum height of 280 ft. above sea-level where the road to Whitehall turns off the State highway. Drill hole No. 5 (Fig. 1) passed through 285 ft. of these sediments before reaching the Hamilton Hills beds, so this gives a minimum measure of their thi kness.

On account of the extension of these sediments through the Hinuera valley and their association with the change in direction of flow of the Waikato there, the writer proposes to call them the Hinuera formation. They are regarded as being upper Pleistocene.

Capping the current-bedded sands and gravels of the Hinuera beds are a series of sands, gravels, and silts which are well exposed where the road from the Public Works Department office at Karapiro branches down the terrace slope to the flats below. Above the Hinuera sands are 10 ft. of fine white sands and silts, the latter containing a few diatoms, suggesting lacustrine deposition. On their eroded surface lie 5 ft. to 6 ft. of rusty gravels and sands, on which is the brown loam discussed earlier. These beds have been mapped along with the Hinuera formation, and represent deposits formed during minor oscillations of the level of the land at the close of the period of depression in which the Hinuera fan was laid down.

Recent Deposits

During recent times eruptions of loose pumiceous ash in the Taupo region covered 8,800 square miles with at least 6 in. of debris (Grange, 1931). Owing to its light nature and incoherence, this material was quickly washed off the higher elevations into the valleys, and the Waikato, which drained so large a part of the area, received a huge load of pumice. The river became choked and was forced to aggrade throughout its length. At Karapiro it aggraded to a level of 70 ft. above present river-level. When maximum loading was passed it cut down again quickly into the loose alluvium.

At Karapiro this material consists of loose pumice sands and gravels. In the higher reaches of the river this deposit is usually light-grey ; but by the time Karapiro is reached inclusions of darker rhyolitic material from the terraces of Hinuera material make the sediments a darker grey ; still they may be distinguished by the inclusion of fragments of carbonized wood that characterize the deposit right from its source.

The section exposed at the sand-pit shows a basement of greywacke, on which remain a few pockets of the subaerial rhyolitic ash of the Hamilton Hills formation. Above are the current-bedded pumice sands and gravels containing fragments of charcoal, with coarse pumice gravels at the base.

This inundation of pumiceous sediments buried a forest growing on the flats bordering the river within the valley carved in the Hinuera beds. The river now takes a different course a mile above the Tunakawa, and has exposed the trunks of the buried forest in its bed. This suggests that the river formerly flowed at a lower level nearby, and there is other evidence to support this.

In the large pot-hole in the river at the dam site, pumice sands and gravels containing, near the bottom, large logs, extended to 98 ft. below present river-level. Holes 28 and 29 (Fig. 2) encountered rock at 45 ft. and 55 ft. respectively below river-level, but hole 27 had not reached rock at 128 ft. and hole 31 passed through pumice and rotten timber from 74 ft. to 100 ft. without reaching rock. No. 30 reached rock at 100 ft.

This appears to prove that, prior to the pumice aggradation, the Waikato followed a course farther towards the Tunakawa, and that it then flowed at a lower level than at present. The accumulation of Recent pumice sediment therefore probably reached to 100 ft. above the earlier river level.

GEOLOGICAL HISTORY

At the end of the Tertiary this region, in common with other parts of New Zealand, was uplifted and dislocated by widespread crustal movements. It is probable that the ranges of greywacke hills came into being at this time, and that they are fault-controlled, though their margins are now masked by younger deposits. The elevation amounted, according to Henderson and Grange (1926), to 900 ft. higher than present sea-level, and a landscape of high relief was sculptured.

The crustal movements in the Pliocene were accompanied by the emplacement, in the central regions, of a succession of vast sheets of rhyolitic material, which formed deposits ranging from loose breccias, through welded tuffs to flows of viscous lava. One of the sheets of welded tuff reached the Karapiro district and filled the depression east of the greywacke ranges, where it was faulted and eroded.

The land now sank till it was 1,000 ft. or more lower than present, and into the valleys and basins were laid down estuarine, lacustrine, and fluviatile deposits of rhyolitic material transported by the streams draining the volcanic terrain to the south. As the eruptions continued spasmodically, subaerial and subaqueous rhyolitic breccias became interbedded with the other sediments. These beds constitute the Hamilton Hills formation, and at Karapiro reached a thickness of at least 350 ft. and probably much more.

Next came an upward movement of the land to about 200 ft. above present level, and the soft beds of the Hamilton Hills formation were quickly eroded subaerially, till a mature topography was attained. At this stage an eruption of andesitic character to the south spread a thin shower of ash over the district. Where exposed at present, this is weathered to a reddish-brown loam, and is known as the Hamilton Shower.

Then further subsidence ensued, and the land sank to approximately 120 ft. lower than present, initiating aggradation once more. The Waikato which at this time flowed to Hauraki Gulf by way of Hinuera valley, built up an expanding flood-plain of loose sands and gravels till it spilled over into the Hamilton basin. Here the mature topography of the Hamilton Hills beds became drowned by the rising flood of loose sediments of the Hinuera beds, which the Waikato laid down in the form of an extensive fan. The unburied remnants of the earlier terrain remain as low, rounded hills, projecting above the level of the plain formed by the fan. Minor oscillations of the land probably occurred after the fan was laid down, causing the deposition of the capping of silts, sands, and gravels that overlie the coarse, current-bedded sediments at Karapiro.

The next stage of events was most important from the engineering point of view. Elevation of the land caused the river to entrench itself in the fan, but as it had meandered freely during aggradation, it now cut down in an entirely new course. Instead of excavating a course along the thickest portion of the fan, it cut down along the south-west margin and became superimposed on the buried toe of the southern greywacke ridge, in which it cut the rocky gorge chosen for the site of the dam. This final elevation ceased at present level.

The sequence and amount of the movements of the land postulated above have been adopted from Henderson and Grange (1926). Failing a knowledge of gradients of the earlier rivers and streams, such as might be obtained from detailed study of drill logs throughout the region, estimates of absolute amount of movement or inferences, whether the movements were uniform or subject to local deformation, could not be given from the evidence

available in such a small area as the Karapiro district. The movements quoted by the above authors appear to fit the facts.

A further short period of aggradation was caused by overloading of the Waikato by loose pumiceous debris from the Recent eruptions in the Taupo region. The choked river built up its course throughout, until the supply of material ceased, when it quickly cut down again through the soft sediments. At Karapiro the aggradation reached 70 ft. above present river-level, and caused the river to change course once more, at the same time deflecting the Hauoira down-stream and lengthening the Tunakawa. Those two streams were also temporarily ponded, and as a result have swampy conditions along part of their courses.

At Karapiro the Waikato appears to be flowing at a level which is 20 ft. to 30 ft. higher than before the Recent pumice invasion. Failing evidence for recent subsidence of the land, or for local deformation to that extent, the writer believes that the river is still engaged in cutting down to its former level, but that the greywacke bar between the mouths of the Tunakawa and Hauoira streams is retarding the process.

RELATION OF GEOLOGY TO ENGINEERING PROBLEMS

The construction of a hydro-electric station involves a series of construction works, each of which cannot be planned without due consideration of the geological factors involved. These are, the excavation of a diversion tunnel, the construction of two temporary coffer dams, the construction of a dam and power-house, and. finally, the impounding of a large volume of water to form a lake. The nature and disposition of the geological formations present and the properties of the individual rock types must be given close attention. The engineering aspects of the geology of the Karapiro district will now be considered.

The Dam Site

Although the building of a dam is not the first stage in the construction of hydro-electric works, the selection of a suitable dam site must obviously be the primary factor in choosing a site. Apart from topographic considerations, the nature of the rocks present will decide not only if a dam can be built at the site, but the type of dam that should be built

At Karapiro the foundations of the dam are being laid on greywackes and argillites of Jurassic age, exposed in a gorge in the Waikato River. These rocks have repeatedly in the past been exposed to weathering, so that they are decomposed to clay and brown, broken rock in the upper levels, and it is necessary that they be excavated till fresh rock is reached. At and below river-level is found fresh rock only, so that maximum excavation is confined to the higher portions of the banks.

The argillites and greywackes occur in alternating bands (see Fig. 3), of which the latter are the stronger rocks. Argillites form the basement within the old river-bed, and at one place there, and again on the right bank, strong faults are in evidence. These faults follow the bedding planes in the argillite, and strike parallel to the river and dip steeply west, so that in the centre of the dam the weight is to be distributed at right angles to the faults. This minimizes the chance of movements, the only likely one being " heave " produced by flow of the finely crushed material of the fault-zone in the centre of the river bed. The resident engineer suggested that this could be obviated by construction of a second cut-off at the downstream toe of the dam.

In the case of the wing wall on the right bank the thrust will be directed at an angle highly inclined to the weak planes in the argillite, but it is proposed to provide for the possibility of movement by suitable modifications in the foundations.

The fault-zones are filled with pug or finely crushed material, which is not likely to be more permeable than the parent rock. The greywacke is likely to be more permeable than the argillite because of its massive structure and intersecting joints, but the permeability is not likely to be great and should be stopped by grouting.

The presence of porous beds of the Hinuera and Hamilton Hills formations suggests that the wing walls be extended to a safe distance. A core wall on the left bank should be extended to the rising greywacke ridge across the road, and on the right bank to give a safe gradient through the porous beds back to the river.

The Power-house Site

The power-house will be located in the bed of the river immediately down-stream from the dam. Its foundation will also be laid on the argillites; but here beyond the removal of sands and gravels from the old river-bed little excavation is required to give fresh rock.

The Diversion Tunnel

At the time of the writer's first visit the diversion tunnel was more than half completed, and an inspection was made of the portion visible. As was to be expected at that level, the rock was of good quality throughout. Several minor faults of the east-west and north-south sets were found, but no major fracture zones. The low permeability of the rocks was evident from the fact that, although the south end of the tunnel was below river and only 25 ft. distant from it, there was practically no seepage of water through the intervening rock.

Karapiro Lake

When formed, Karapiro Lake will reach a level of 176 ft. above sea-level, and will extend to Arapuni. For the most part it will be bordered by young, porous sediments of fluviatile origin. These, however, are contained within larger valleys of older rocks, except for two localities, where leakage may be expected. One of these is through Hinuera valley along the old course of the Waikato, through the porous Hinuera sediments. The other is at Karapiro itself, along the earlier course of the river north-east of the dam. In the former case leakage will be negligible, but the latter is more serious.

An arm of the lake will extend for some distance up the Tunakawa valley, and will thus bring its margin within 20 chains of Karapiro Stream, where it flows at a level of 117 ft. above sea-level. The intervening country consists of highly porous sands and gravels of the Hinuera formation. In a former report to the Public Works Department the writer pointed out the possibility of leakage and scour developing in this direction, and also north-west to the Waikato. Dr. Henderson later examined the area, and suggested that bores be sunk across the Tunakawa-Karapiro sector to investigate the thickness of the Hinuera beds and the ground-water table, and that a geophysical investigation be made to obtain a section across the entire gap by the seismic method. This has since been done, and at the time of the writer's last visit the first seven holes had been drilled. Their results are given in an earlier section.

From the small gully in Tunakawa valley between drill holes Nos. 1 and 2 (Fig. 1), west to the Waikato River, the fall from lake-level to river-level will be 1 in 19. It was thought previously that the basement greywackes of the dam site extended through this section at sufficiently high level to counteract leakage, but this has been disproved by those holes. It has been found, however, that, although the water-level in Nos. 2 and 3 was approximately 79 ft. above sea-level, that in Nos. 4 to 7 was over 50 ft. higher. The former water-level is directly related to the Waikato, from which the bottoms of the holes are separated only by permeable sands and gravels. The ground-water table of the Tunakawa-Karapiro section is governed by another factor.

It is most likely that the Hamilton Ash shower, which covers the low hills of the Hamilton Hills formation and extends underground on their buried slopes, forms an impermeable layer upon which is perched the water-level of Drill holes 4 to 7 in the Hinuera sands and gravels. In addition, it was mentioned previously that the ryholitic breccia found in holes 2 and 3 and the cutting nearby might possibly be the same as that met at 285 ft. in No. 5, in which case it forms a deposit with more or less similar disposition to the Hamilton shower. Its degree of consolidation, together with its total lack of sorting makes it less permeable than the sand and gravel members, and it will thus also restrict the movement of ground water. It therefore appears probable that at any rate the material of the Hamilton shower forms an impermeable barrier between the Hinuera beds and the permeable members of the Hamilton Hills formation, so that there is little likelihood of serious leakage west to the Waikato River through the Hamilton Hills beds.

In this connection hole No. 1 passed through 85 ft. of loose sands and gravels, probably belonging to the Hinuera formation before what is probably the Hamilton shower was met. This level will be just safe, and it is suggested that the Hinuera beds here thin to the north-west. The Hamilton shower will be broken along the course the stream followed at the time the ash shower occurred, but the buried valley must be half a mile or more north-east of the river and at a sufficiently low level to make leakage negligible. A check on the water-levels in drill holes 2 and 3 during filling of the lake will indicate any leakage in this direction.

From the lake-level in the Tunakawa to the flat bordering Karapiro Stream at the nearest point is a fall of 1 in 30. The well-sorted, coarse sands and gravels of the Hinuera formation are likely to be extremely permeable, and leakage is certain to occur across this section. Were springs to emerge at sufficiently high level in the Karapiro valley as to cause scour in the Hinuera sediments the results would be serious.

Between drill holes 5 and 6 the hydraulic gradient shows a fall of 1 in 200, and if continued south will pass 18 ft. beneath Tunakawa Stream, which is thus apparently perched on a bed of swampy material. When Karapiro lake is filled, escape of water from the Tunakawa valley will modify this hydraulic gradient. Owing to the high permeability of the sands and gravels it is most likely that the effect will be merely to steepen the hydraulic gradient, in which case the water leaking away will escape into the Karapiro at or near water-level in that stream. If, on the other hand, the entire hydraulic gradient is both steepened and raised, springs will emerge at high level in the Karapiro valley, and if they are of sufficient volume scour may develop. In any case the filling of the lake will raise the water-table north and north-west of the Tunakawa and there will be a continuous escape of water in that direction.

By recording measurements of water-level in the holes across this section while the lake is being filled it will be possible to check the movements of the water-table. In a former report the writer suggested that the flow of water in Karapiro Stream could be measured before and after filling the lake as a means of estimating the amount of water escaping, though this would not give the total quantity. In such a case it will be desirable to measure the flow in the Karapiro both above and below the portion under discussion.

In prospecting the gap between the dam site and Karapiro Stream by geophysical methods it is desirable that the possible extent of the welded rhyolite tuff at depth be not neglected. If it was faulted against the greywacke, as has been suggested, it may be present at depth through the gap, unless the greywacke originally formed a north-south ridge across which the rhyolite did not extend. Otherwise the failure of hole No. 5 to locate it within 320 ft. of the surface suggests its removal by erosion before the Hamilton Hills beds were laid down. It appears likely that the pre-Hamilton Hills depression, which is apparently fairly deep, was controlled by faulting along the north-east margin.

ACKNOWLEDGMENTS

In conclusion, the writer expresses appreciation of assistance rendered by Mr. Gilkison, Resident Engineer, Karapiro, and members of his staff in providing plans, transport, and other assistance from time to time, and by Dr. Henderson and Mr. N. H. Taylor in helpful discussion in the preparation of this paper.

REFERENCES

BARTRUM, J. A. (1937): Jurassic Fossil from Motumaoho Quarry, near Morrinsville. *N.Z. J. Sci. & Tech.*, *19*, 458 9.

CUSSEN, L. (1889): Notes on the Waikato River Basins. *Trans. N.Z. Inst.*, *21*, 406–16.

——— (1894): Notes on the Piako and Waikato River Basins. *Trans. N.Z. Inst.*, *26*, 398–407.

GRANGE, L. I. (1931): Volcanic-ash Showers. *N.Z. J. Sci. & Tech.*, *12*, 228–40.

——— (1937): The Geology of the Rotorua-Taupo Subdivision, Rotorua and Kaimanawa Divisions. *N.Z.G.S. Bull. 37.*

GRANGE, L. I., and TAYLOR, N. H. (1931): Reconnaissance Soil Survey of the Central Part of the North Island. *N.Z.G.S. 25th Ann. Rept.*, pp. 7–8.

HENDERSON, J. (1913): The Geology of the Aroha Subdivision, Hauraki, Auckland. *N.Z.G.S. Bull. 16.*

——— (1918): Notes on the Geology of the Waikato Valley near Maungatautari. *N.Z. J. Sci. & Tech.*, *1*, 56–60.

HENDERSON, J., and GRANGE, L. I. (1926): The Geology of the Huntly-Kawhia Subdivision, Pirongia and Hauraki Divisions. *N.Z.G.S. Bull. 28.*

HOCHSTETTER, F. VON (1867): New Zealand.

MARSHALL, P. (1935): Acid Rocks of the Taupo-Rotorua Volcanic District. *Trans. Roy. Soc. N.Z. 64*, 1–44.

MEAD, A. D. (1938): Geology of the Te Miro Basin, Auckland Province. *N.Z. J. Sci. & Tech.*, *19*, 488–96.

MURRAY, G. T. (1919): The Waikato River. *Proc. N.Z. Soc. Civ. Eng.*, *5*, 226–42.

TAYLOR, N. H. (1938): Water-supplies of Farms and Dairy Factories in Hamilton Basin and Hauraki Lowland. *Dept. S. and I.R. Bull. 48.*

TAYLOR, N. H., and GRANGE, L. I. (1939): Soils and Agriculture of Part of Waipa County. *Dept. S. and I.R. Bull. 76*, 12–23.

APPENDIX

Since writing this paper the writer has revisited Karapiro and re-examined closely the dam site and surroundings. In excavating for the foundations of the thrust block on the left bank a subsidiary fault, striking a little east of

north and dipping with arcuate plane east towards the strong fault in the former river-bed, was encountered. On the rising slope of the foundation for the thrust block, the rock east of this fault plane showed a tendency to slip, and had therefore to be removed. Another fault, with strike east-south-east and dip about 40° to the south, was also encountered. This fault apparently defined the small gully existing formerly along the line of the dam on the left bank.

The Taipa Stream has been diverted south-east into the Hauoira, and for part of its new course flows in an open channel alongside the road south-west of the dam. The channel has been excavated in rhyolitic breccia, which in places is quite poorly consolidated, but which apparently grades into the well-consolidated tuff exposed in the gorge in the Hauoira Stream. A close inspection of cuttings along the State highway from Karapiro to the Maungatautari gorge revealed also a great variation not only in the degree of consolidation but also in texture throughout what appears to be a single sheet of rhyolitic tuff. It varies from what appears to be welded tuff to loosely compacted material. It closely resembles the breccia outcropping alongside the access road to Karapiro, and again in the road cutting 30 chains to 40 chains north-west of the dam, but does not resemble the breccia exposed in the excavations at the dam site, and its relationship to the latter is not evident.

The writer had previously, on the evidence of the presence of rhyolitic tuffs of different degree of consolidation, suspected the existence of two tuffs, the older of which has been mapped as welded tuff and was thought to ante-date the sedimentaries of the Hamilton Hills beds, while the poorly consolidated younger one was included with the Hamilton Hills group. It now therefore appears likely that the tuffs outcropping in the gorge of the Hauoira, east of the Karapiro, alongside the Karapiro access road and north-west of the dam, all form part of a single sheet. In this case drill holes Nos. 2 and 3 prove that the tuff overlies the Hamilton Hills sedimentary beds. Petrological work would probably be necessary to establish the correlation of the outcrops.

This amended conception would call for modification of the geological history to the extent that either the rhyolitic tuff belongs to the youngest phase of rhyolitic eruption, or else the Hamilton Hills beds are entirely Pliocene. The disparity in level of the base of the sheet of tuff in that case between the site of drill holes Nos. 2 and 3 and the Hauoira Stream suggests the tuff to have been emplaced on an eroded surface of Hamilton Hills beds. The complete history of this section is still, therefore, dependent on the correlation or otherwise of the rhyolitic tuffs.

GEOPHYSICAL INVESTIGATIONS AND DRILLING RESULTS EAST OF KARAPIRO DAM

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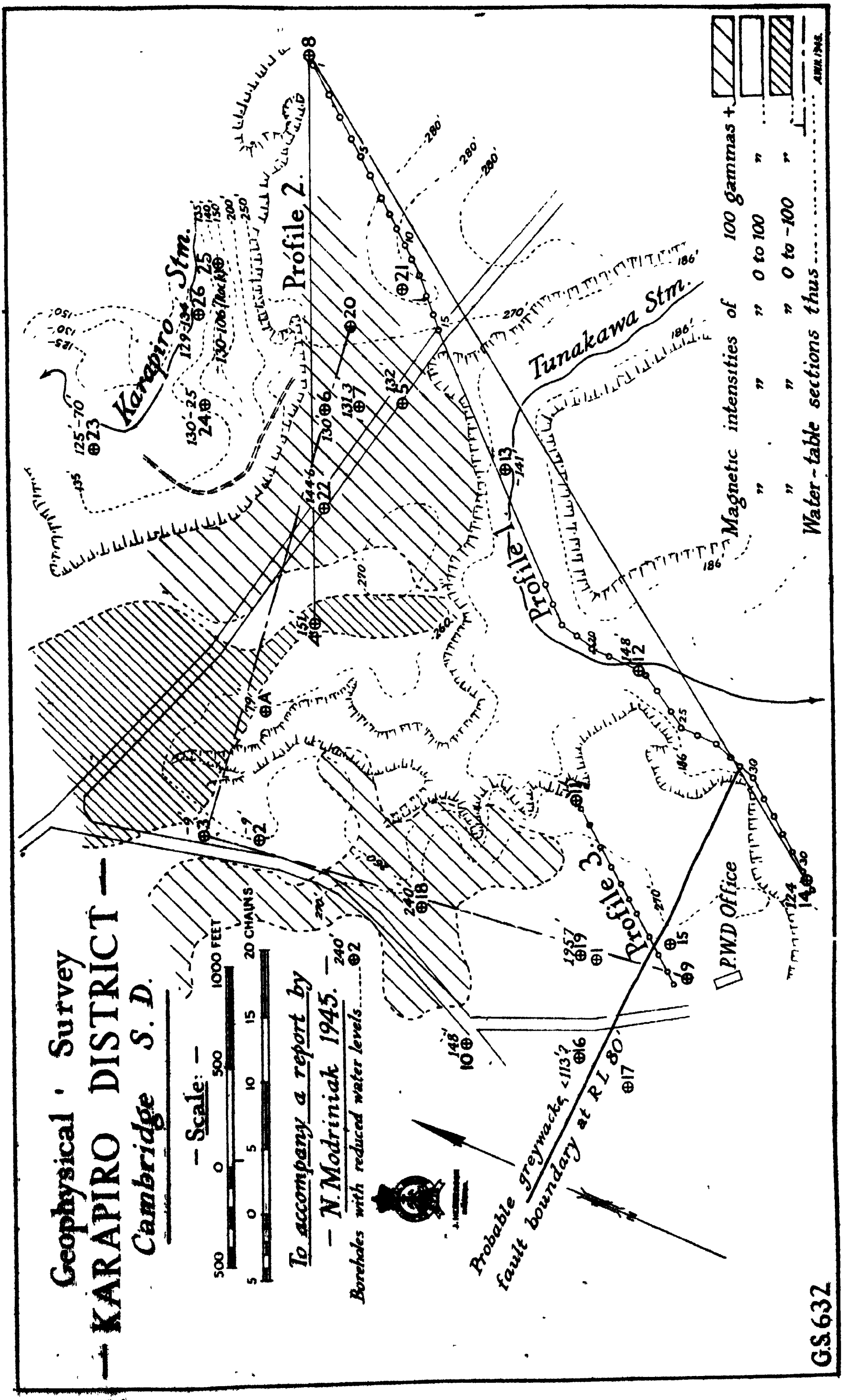
Summary

Results of magnetic and seismic observations are shown on the maps and briefly discussed. Positions of bores are shown, logs tabulated, and important implications pointed out. Trenches indicate that the depressions on the pumice terrace east of Karapiro Dam are probably of Maori origin.

INTRODUCTION

WHEN Karapiro Dam is filled, the water in part will be contained within banks of unconsolidated and readily permeable pumiceous gravelly sands so abundant in the Hamilton basin. On the east side of the Waikato River the Tunakawa and Karapiro streams are deeply cut in these sands and have steep valley sides which are separated by undissected flats. Some 60 chains north-east from the dam the flats between the valleys are less than 1,000 ft. wide, and when the dam is full the hydraulic gradient from the flood-level of the lake extending up the Tunakawa to the valley floor of the Karapiro will be about 1 in 28. In order that the engineers might have data on which they could take appropriate measures to prevent undue seepage, geophysical examinations and drillings were undertaken in and about the area.

North of the State highway, which traverses the neck between the Tunakawa and Karapiro streams, there are numerous rounded depressions on the surface of the flat. These, which are locally known as "Maori holes," range from 20 ft. to 120 ft. across and from 2 ft. to 12 ft. deep. They are similar in every way to the depressions of which Lawrence Cussen (*Trans. N.Z. Inst.*, *21*, 1889, p. 411) wrote : "Characteristic of the middle Waikato Basin are the numerous funnel-shaped holes to be seen everywhere throughout the alluvial deposits. They were formed by the subterranean or soil waters in passing along beneath the surface of the earth. They create small caverns, and, finally, underground streams which draw away the loose material from the surface and frequently form symmetrical funnel-shaped holes—the "pot-holes" of the settlers." By extending the drawing-away process to the deeper sands some observers have suggested that these depressions are analogous to the collapse holes of limestone regions. On the other hand, Elsdon Best, on pp. 60–62 of his "Maori Agriculture" (*Dom. Mus.*, *Bull. 9*, 1925) quotes evidence that the Maoris used to excavate gravelly sand to spread on their gardens to improve soil texture for the cultivation of the kumara. Grange, Taylor, and Sutherland (*D.S.I.R. Bull. 76*, 1939) mapped considerable areas of such Maori-made soils in the Waikato basin and (p. 39) describe the conical holes from which the gravelly sand was obtained.


Geophysical · Survey
— KARAPIRO DISTRICT —
Cambridge S. D.
— Scale: —
1000 FEET
20 CHAINS
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Boreholes with reduced water levels
Magnetic intensities of 100 gammas +
" " " 0 to 100
" " " 0 to -100
Water-table sections thus
Karapiro Stm.
Tunakawa Stm.
Profile 1.
Profile 2.
Profile 3.
P.W.D Office
Probable greywacke <113'
fault boundary at R.L 80'
G.S. 632

The Public Works Department officers cut trenches across three of these holes near Karapiro, and Dr. L. Grange examined these cuts as well as the soils adjacent to the holes. In a memorandum dated 30th April, 1945, to the Hydro-electric Branch of the Public Works Department he writes that the "soil surrounding each of the holes for a distance of a few chains is a gravelly sand which lies on the top of a yellow brown sandy loam . . . Farther away from the holes the gravelly sand is absent and the soil is a sandy loam." He also notes that the "gravel beds at the bottom of the holes are undisturbed right across the section." He concludes that the shallow depressions at Karapiro were made by the Maoris. A deeply entrenched gully known as Poplar Gully leads from the terrace north of the main highway to the Karapiro basin. Its probable origin due to sub-surface erosion was discussed by the writer in the previous report.

GEOPHYSICAL OBSERVATIONS

Absence of outcrops of the older formations between the dam site and Karapiro Stream made it desirable to investigate the locality geophysically. The object of the survey was to determine the distribution and contour of the more consolidated rocks buried beneath the pumice sands and, if possible, to elucidate their structure. Of practical value in the present construction job are the rock elevations at or about the approximate water-level of the Waikato River at the dam site—*i.e.*, 80 ft. above sea-level.

Magnetic Work.—The map (Fig. 1) shows the positions of the observation stations and the distribution of magnetic intensities of more than 100 gamma, between 100 and zero, and between zero and −100 gamma.

There are two areas of higher magnetic intensity. The eastern one is thought to be brought about by the extension under the unconsolidated sands of the welded rhyolite tuff outcrops in the Karapiro valley. These tuffs are known to be the most strongly magnetic rocks of the district.

The area of high magnetic value on and near the road from the dam-site to the State highway is not so readily accounted for. The welded tuffs may occur in depth, but the wells drilled in this area did not penetrate through the more consolidated fluviatile deposits of the Hamilton Hills beds outcropping at Well No. 3, which reached a depth of 285 ft.

The belt of negative values may indicate the trend of a sand-filled depression or valley between the areas of higher intensity.

Seismic Work.—Seismic studies were carried out along selected lines shown on the plan, and the results are represented graphically in profiles (Fig. 2). Seismic line 1 extends south-west between Bores 8 and 14, both of which reached greywacke and so provide a base of reference. Line 3, nearly parallel with the first, was begun from Bore 9, about 12 chains north-west from Bore 14, but was discontinued owing to difficulties of access in the Karapiro valley. Another line from Bore 8 extends along the flats immediately south of the Karapiro valley.

The transmission of elastic waves was poor above ground water in the unconsolidated sands through which a velocity as low as 1,500 ft. per second was recorded. The velocity in the sands below ground water was 4,000 ft.

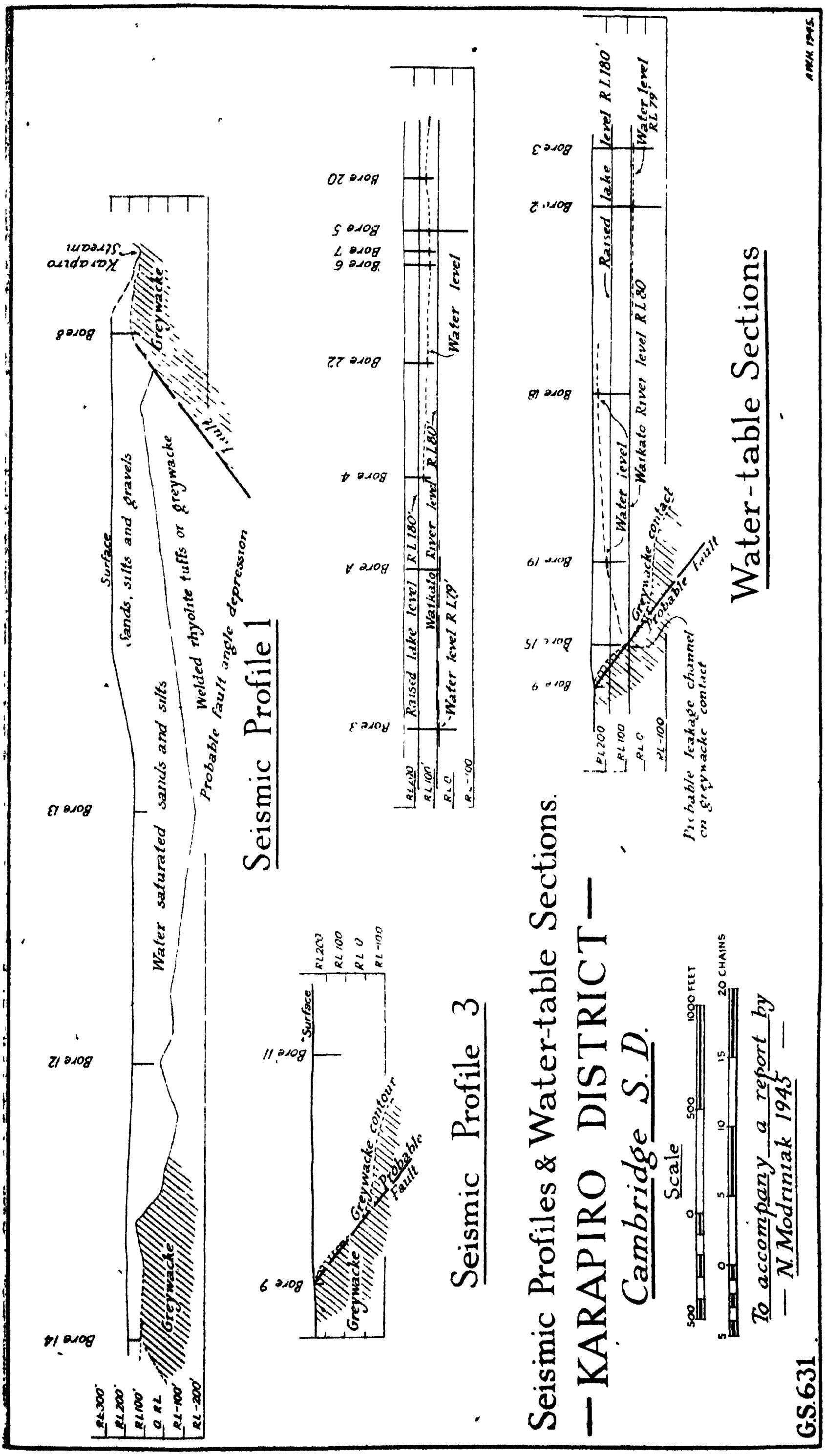
Seismic Profile 1
Seismic Profile 3
Water-table Sections
Seismic Profiles & Water-table Sections.
— KARAPIRO DISTRICT —
Cambridge S.D.
Scale
To accompany a report by
— N. Modriniak 1945 —
GS.631

FIG. 2.

per second, and this was assumed as the all-over average velocity in the surface beds for the calculation of the sub-surface rock contours. Greywacke, the basement rock between Point 36 and Bore 13, has velocities between 10,000 ft. and 15,000 ft. per second. Westward from Bore 8 the rock surface may consist either of greywacke or of the welded rhyolitic tuffs outcropping in the Karapiro valley. If these latter are present, as the magnetic work suggests, it is reasonable to assume that they are down-faulted and occupy a fault-angle depression. The whole section suggests a series of step-faults with the greatest depression to the east. The results of all the lines are incorporated in the profile.

Only by resorting to shooting at night was it possible to reduce the noise level to reasonable limits. The recording of a negative velocity between Bores 9 and 11 is unique. Such a fictitious negative velocity is possible if the angle of incidence is smaller than the slope angle of the formation. From the scanty information available the angle of incidence was determined as about 30° and the slope angle at 45° though this latter may be as high as 51°. The greywacke reached in Bore 9 slopes steeply northward and is probably the face of a fault. An attempt has been made by using the seismic profile and surface information to outline the sub-surface 80 ft. contour of the hard-rock.

LEVELS OF WATER TABLES

Generally it can be stated that the unconsolidated gravelly sands that form the high-level flats are highly permeable. Casing had invariably to be used to ensure a return of the drilling water until the water-table was reached, and even below this level mud was required in some wells to ensure return. The beds, of course, stand better when saturated, but in several wells the walls kept falling in below ground-water level. The Hamilton Hills deposits in general stand better and are less porous, but they also gave trouble owing to loss of water and collapsing walls.

Bore specimens are available on which tests of porosity and transmissibility can be made. In view, however, of the irregular sedimentation of the several members it is doubtful if such tests would furnish practical results; tests of this kind are best carried out where possible with the beds in place.

A table of the driller's logs is incorporated in this report. The reduced level or R.L. is the level in feet from datum, which is sea-level.

A section through Bores 9, 15, 19, and 18 has been prepared. Position of bores, depths, and water-levels are shown on the map. The hydraulic gradient near the greywacke contact is steep, suggesting drainage along the contact to lower levels, probably to the water-level situated in the Hamilton beds at R.L. 79, which was explored by Bores 2, 3, and A. The majority of bore-holes have been lined with casing so as to permit observations of the water-table at raised lake level. The hydraulic gradient between the Tunakawa and Karapiro streams will be 1 in 26, and along the section of the greywacke contact between the Public Works Department office and the Waikato River approximately 1 in 15.

TABLE OF BORE LOGS: KARAPIRO

Bore No.	Reduced Surface Level.	Depth from Surface.	Water-level from Surface.	Reduced Water-level.	Comments (all Depths in Feet).
1	264·8	185	..	..	Highly permeable strata to 85 ft. from surface. Water returned to surface after casing. At lower levels water return insufficient to clear well, walls of which kept falling in.
2	258·4	325	179·2	79·2	Upper porous sands to 126. Bore below open, with good water return.
3	265·9	285	187	78·9	Porous strata to 108, below which conditions similar to Bore 2.
4	265·8	145	114·1	151	Porous strata and casing to 108. Below walls kept falling in, mudding required to get water return.
5	267·1	325	135·6	132	Porous strata and casing to 131. Between 230 and 260 no water return, mud used to 325 where fine sands fell in.
6	267·9	165	138	130	With casing at 65, beds below absorbed water at 4 gal. in 15 sec. Casing to 105, loss 4 gal. in 35 sec. Casing to 165, loss more than 2 in. hose could supply. Mudding used below 165.
7	267·5	175	136·2	131·3	Very porous to 46 and at 60. Mud used. Conditions otherwise similar to Bore 6.
8	280	115	..	..	Greywacke at R.L. 165.
9	260	55	..	..	Weathered greywacke at R.L. 205.
10	244	195	96	148	Porous strata to 66, then water-tight to 135.
11	266	165	118	148	Porous strata to 46, but little loss. Good return at greater depth.
12	151·7	105	22	129·7	Cased to 93. 70 ft. from Tunakawa.
13	152	65	11	141	10 ft. from Tunakawa.
14	165	65	41	124	No return of water till casing driven to 57 on greywacke.
15	272·6	152	116	156·6	Greywacke at R.L. 123. Six weeks after boring well was dry.
16	243	156	70	173	Greywacke at R.L. 83 weathered to R.L. 165. Highly permeable to 34 and water lost at 60 from surface. Five weeks after boring well filled with sand to R.L. 113 and dry.
17	240	53	0	240	Greywacke at 35 ft., weathered to 50 ft. No water lost.
18	280	205	40	240	Rhyolite tuff to 75; pumice sand 75–105; coarse gravel 105–155; clays and sands 155–165; gravel and sand 165–205. Beds tight throughout.
19	265·7	165	70	195·7	Cased to 70 ft., then good return. Water-level after drilling 54, one month later 70.
20	273	155	123·5	149·5	10,000 gal. of clean water without return, even when cased to 75. Good return with mud.
21	260	175	116·6	143·4	Cased to 70. No return without mud.
22	266	155	121·6	144·4	No return without mud.
A	260	192	180·6	79·6	Private bore on Mr. Short's farm.

COAL RESOURCES OF THE KAWAKAWA-WAIOMIO AREA, NORTH AUCKLAND

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Summary

The coal-measures at Kawakawa occur at the base of the Whangarei Series of mid-Tertiary age, as a north-west strip three and a half miles long and up to a mile wide. Throughout, the beds dip gently south-west to west. They overlap from a basement of ancient greywackes of the Waipapa Series on the east on to claystones, mudstones, sandstones and limestones, of the Onerahi Series to the west. The coal is thickest along the eastern margin, where the former basement underlies the coal beds, and thins to the west.

The coal in the Kawakawa area thinned to the west and south in the workings, and drillholes beyond those limits showed coal to be thin or absent, and further development useless. To the north the evidence of drillholes and accounts, both written and verbal, are conflicting; but, on the whole, adverse to the possible extension of good coal. A site, however, has been indicated at which the maximum amount of information can be obtained from a drillhole to put the issue beyond doubt.

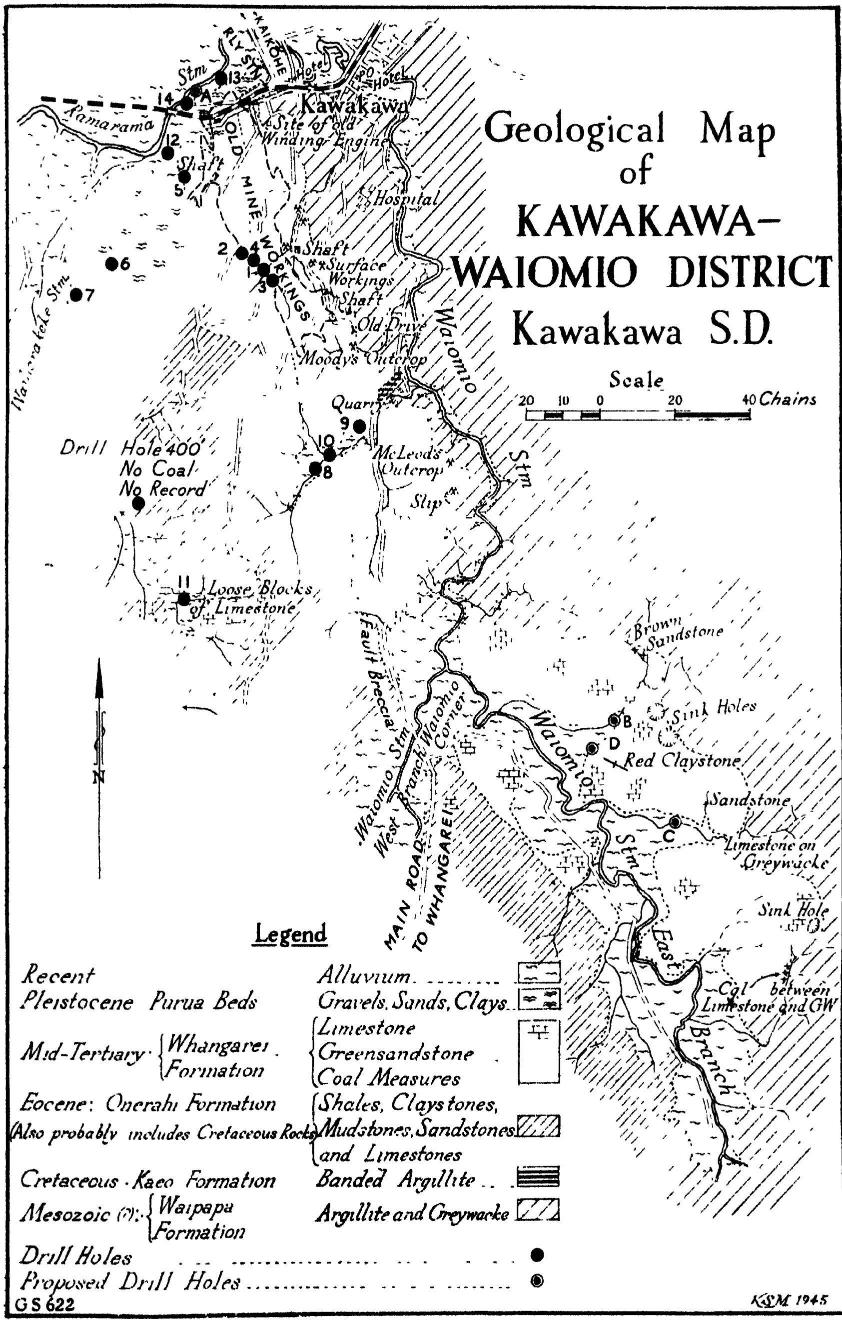
The other possibility for locating coal is in the Waiomio basin, to the south-east of the Kawakawa area, along the strike of the strip of Whangarei sediments. Though no outcrops of coal-measures have been found, their presence cannot be disproved short of drilling, which would, therefore, be purely speculative. The association of the thickest coal with the greywacke basement at Kawakawa suggests that the eastern portion of the Waiomio basin be selected for boring, and two alternative sites have been indicated. Another site has been indicated to test the presence of faulting should coal be discovered.

INTRODUCTION

KAWAKAWA Township, in the south-east corner of Kawakawa Survey District, lies on the main north road 37 miles from Whangarei, and also on the railway-line from Auckland to Opua, being eight miles from the latter terminus. In the early days a coalfield was opened in the area lying within a mile south-west of the town, and until 1882 the Kawakawa Coal-mine led coal production in New Zealand.

"In February, 1861, Maori kauri-resin diggers reported coal cropping out in the bed of a small stream, evidently that one which flows through the present township between the school and the hospital. By 1865 a trial shaft and a considerable amount of boring had been completed, and the extraction of coal by the Bay of Islands Coal Company had commenced. At the end of 1871 a total of 90,000 tons had been exported from the port of Opua on the Bay of Islands, and by 1886 the total output had increased to 615,000 tons. For the next twelve years production was continuous, although there were considerable variations in the quantity exported from year to year. In 1899 a sharp decline in output from 10,600 tons to 4,000 tons. indicated the approaching exhaustion of the known coal-bearing area, and, thereafter, the decline continued until 1913, when the mine closed. In all, some 870,000 tons were extracted from an area of about 130 acres."

The above extract from Ferrar (1925, p. 107) briefly outlines the history of coal production in the Kawakawa field. Between 1922 and 1926, 3,085 tons were taken out from pillars in the old workings and from seams in the area south of the hospital.



Geological Map of KAWAKAWA-WAIOMIO DISTRICT Kawakawa S.D.
Scale
20 10 0 20 40 Chains
Kawakawa
Hotel
P.O. Hotel
Site of old Winding Engine
OLD MINE WORKINGS
Shaft
Hospital
Surface Workings
Old Drive
Moody's Outcrop
Quarry
McLeod's Outcrop
Slip
Drill Hole 400' No Coal No Record
Loose Blocks of Limestone
Fault Breccia
Waiomio Stm
Waiomio Corner
West Branch Waiomio Stm
MAIN ROAD TO WHANGAREI
Brown Sandstone
Sink Holes
Red Claystone
Sandstone
Limestone on Greywacke
Sink Hole
Coal between Limestone and GW
East Branch
Kamarama
Waiomio Stm
N
Legend
Recent — Alluvium
Pleistocene Purua Beds — Gravels, Sands, Clays
Mid-Tertiary Whangarei Formation — Limestone, Greensandstone, Coal Measures
Eocene: Onerahi Formation (Also probably includes Cretaceous Rocks) — Shales, Claystones, Mudstones, Sandstones and Limestones
Cretaceous - Kaeo Formation — Banded Argillite
Mesozoic (?): Waipapa Formation — Argillite and Greywacke
Drill Holes
Proposed Drill Holes
G S 622
KSM 1945

The coal itself was semi-bituminous, favoured for steaming purposes, and with better coking properties than the other North Auckland coals. It was taken three miles by rail to the Kawakawa River, whence it was barged to Opua and shipped farther afield.

Requests from local residents in recent years to have the area geologically re-investigated reached a climax with the drive for increased coal production. It has been contended that coal exists in sufficient quantity to warrant opening a new mine. The writer accordingly visited the area for short periods in July and September, 1943, and again in June, 1944.

Possible extensions of workable coal were discussed by Ferrar (1925), and the conclusions reached are believed to be substantially correct. However, the writer has mapped the area in greater detail, and additional data are presented and discussed in this paper.

Several local residents, notably Messrs. Dodd and Fleet, and the late Mr. Charles Wyatt, very kindly pointed out features of the old workings on the ground and gave useful information.

PREVIOUS WORK

Hector (1866) reported a total thickness of coal amounting to 13 ft. 6 in. encountered in an experimental shaft sunk 20 yards from the original outcrop in the gully south of the township. Presumably this shaft was sunk in 1865. In addition, twenty-eight bores had been sunk over the area nearby, the deepest being 130 ft. An appendix gives data concerning the properties and tests of the coal, experiments having been made at the Auckland Gasworks.

Hutton (1872) shows a sketch-plan in which the boundary of the coal formation, various bore sites, mine locations, and the supposed line of a fault are mapped. He reported that a mine had been opened at the outcrop of coal at the Waiomio Swamp. This presumably is in the small gully where the winding engine was installed, 10 to 15 chains south of the present railway-station. The coal was followed, " N. by E.," by a gallery for 27 chains, till a fault was met with a throw of approximately 70 ft. down to the south. This is apparently a mistake, and the direction of working should be " S. by E." The coal thinned in this direction. Elsewhere the thickness varied from 16 ft. to 7 ft., and averaged 12½ ft., and the coal dipped W. by N. one in six. The logs of two holes adjacent to the fault are quoted, and it is suggested that the fault accounts for the fact that Moody's outcrop is about 70 ft. lower than the original seam.

A later sketch-plan was published by Denniston (1877) to show the location of three holes whose logs he described in detail. Near the present school site the seam was stated to be 8 ft. thick, to be overlain by soft, green sandstone, and to dip west to north-west. Northward the coal undulated from 6 ft. to 10 ft. in thickness. He suggested that further extension of the mine to the north beneath the swamp would interfere with the safety of the mine, and that the coal would thin, as the older slates rose in that direction. Hector (1877) considered that the future of the mine would depend on the development south of the fault, as the engine dip and lower level had been developed to about the maximum possible with the existing pumping shaft and facilities.

Cox (1882) discussed the geology of the new dip section running south-west from the engine, where a pumping shaft was sunk in 1879. He explained the thinning of the coal towards the dip (south-west) by postulating a local " ridge " in the old slate floor, beyond the crest of which the coal would

be found to thicken again. Cox thought there might be an unconformity between the calcareous sandstone forming the roof in the sinking pit of the pumping shaft and the green sandstone that forms the roof to the east in the old workings, but he stated that he was not satisfied on this point. His section showed the suggested relation. He also mentioned the Waiomio limestone, which he found resting on the old slates, and considered it to be unconformable to the coal-measures.

The most comprehensive report to date was given by McKay (1884), who included a plan showing the location of four diamond-drill holes sunk at points beyond the margins of the old workings. He discussed the logs of these holes and their bearing on the stratigraphy from the point of view of locating more coal. He drew a section showing the coal-measures resting on a basement of Devonian slates, and overlain by greensand and calcareous sandstone passing up to white limestone. Above the limestone he placed shale with flints, hydraulic limestone, upper greensands, and grey marls, in that order. The shales and claystone between the Waiomio east and west branches and 20 chains north-west of the East Waiomio turnoff he included in the beds overlying the Waiomio limestone.

McKay stated that the coal thinned south of Moody's outcrop, and also to the dip in the main workings, to the north beneath the swamp, mining would be dangerous. He considered, however, that the uneven thickness of the coal was due to irregularities in the surface of the basement rocks, and that there was a tendency for the coal to thicken again towards the Waiharakeke Swamp for certain reasons. However, the coal would be found only at great depth in this direction, and he recommended a bore site west of the swamp where coal should be found at 700 ft.

Hector (1894) followed McKay in placing the hydraulic limestone series above the coal-measures, but he differed in detail by placing an upper calcareous sandstone above the hydraulic limestone, in an interpretation of the section through the length of the engine dip and the two diamond-drill holes to the west. Another section at the south end of the workings showed the limestone to be unconformable to the greensands, following Cox (1882). A sketch-plan shows the sites of the diamond-drill holes mentioned by McKay with reference to the old workings, and the detailed logs are given.

McKay (1898) apparently changed his mind about locating more coal in a report on drilling operations west of Waiharakeke Swamp by the Russell Syndicate. He pointed out that the beds overlying the slates at Turntable Hill had no coal at the base, and as the hole already commenced would have to go to 1,000 ft. to reach coal in any case he advised that drilling be stopped. He still thought there might be a chance of obtaining coal at shallower depths farther west round the margins of the basin, and possibly also in the basin of Waiomio Creek.

Ferrar (1925) separated the beds overlying the old basement rocks into the Onerahi Series of Upper Cretaceous age, including limestones, claystones, shales, greensands, &c., and the Whangarei Series of Miocene and Oligocene age, including the coal-measures, with unconformities separating the three rock groups. The Whangarei Series passes from the basal coal-measures up into marine sandstones, then to limestones or calcareous sandstones into which the limestones grade laterally, and, finally, calcareous mudstones and flints near their base. Ferrar also referred to "coloured clays" overlying the calcareous sandstone in the Kawakawa area. He retained the unconformity first suggested by Cox between the limestone or calcareous sandstone and the underlying greensands.

Ferrar's map of the Kawakawa Coalfield shows a strip of Whangarei beds trending north-west from Waiomio to south-west of Kawakawa Township to the edge of the swamp there. Two lobes extend south-west from this strip, one at the mouth of the Waiharakeke Stream, and the other three-quarters of a mile to the south. Both are cut off by a fault following the Waiharakeke Stream. Ferrar considered that any coal remaining under the swamp west of Kawakawa would be unsafe to work. He stated that the workings in that direction encountered what was thought to be a fault, but may actually have been alluvial deposits, as there was an inrush of water. He suggested that the most likely extension of coal would be found in the upper Waiomio basin, where he recommended prospecting by drilling.

Other information concerning mining operations is to be found in several early papers relating to minerals and mining, published by the Mines Department in their annual statements. An unpublished private report by J. R. Chaffey (1906) on other properties in the Kawakawa district discussed the geography of the region and the land tenure rather than the geology, and merely recommends an indefinite boring programme.

PHYSIOGRAPHY AND STRUCTURE

At the end of the Tertiary period the North Auckland area seems to have undergone peneplanation. Then at the close, intermittent faulting, accompanied by volcanic outbursts, modified the land surface, which was also elevated and subjected to renewed erosion. The disrupted remnants of the old peneplain form many plateaux throughout the region, especially where preserved in the more resistant greywacke country.

In the Kawakawa area a major fault with throw of over 500 ft. trends east-north-east and defines the valley of the Kawakawa River, which flows in that direction to the Bay of Islands in an alluviated fault-angle depression. The township of Kawakawa is on the downthrow side of the fault, at the foot of the slopes rising away from the alluvial plain. The old peneplain had bevelled alike greywackes of the Waipapa Series, limestones and sandstones of the Whangarei Series, and limestones, mudstones, and claystones of the Onerahi Series, all these having been previously faulted and folded along the lines trending north-west before peneplanation commenced. The present contact of the Whangarei beds with the greywacke trends south-east from Kawakawa School to Waiomio, and the plane of contact dips south-west, oblique to the Pliocene peneplain.

The Whangarei strata, which previously extended north-east across the greywacke, were removed during the Pliocene ; and the dissected surface of the greywacke rises gradually to the east. To the south-west Whangarei beds overlap on Onerahi rocks. The former beds are in a strip one mile wide, and are defined along the west margin by both faulting and folding. The Onerahi terrain, which presents little resistance to erosion, forms wide ridges of low relief, but the area covered by Whangarei beds, south-west of Kawakawa, still retains a vestige of accordant summit levels, despite the dissection.

Waiomio Stream, in its lowest course, is entrenched in greywacke and follows the former line of contact of those beds with the Whangarei beds. Three miles up it divides, the east branch heading back along the centre of the strip of Whangarei limestone to the greywacke beyond, and the west branch heading back into Onerahi country.

Although the north-east contact of the Whangarei sediments with the greywacke is, in places, apparently steeply dipping, there do not appear to be any signs of faulting along it. The basal beds containing the coal-measures

were apparently laid down along a trough following the contact of the greywacke with the Onerahi beds, which probably was fault-defined. This relationship is a striking one throughout the North Auckland coalfields.

The contact of the Whangarei strata with those of the Onerahi on the south-west is certainly at least, in part, defined by faulting. Lack of knowledge of the complete stratigraphic relations makes accurate mapping impossible, especially in the northern sector.

Ferrar (1925) showed remnants of Pleistocene deposits of the Purua Series capping several ridges west of the Kawakawa area, and it appears fairly certain that patches of similar beds exist much nearer to the township.

RECORDS OF LOGS

Records of eleven drillhole logs are available, and the writer has recorded the approximate positions of these on the map. Four of these sites were marked by Ferrar (1925) on his maps, but there appear to have been inaccuracies in his base maps, which cannot be reconciled with those used by the present writer, so the relative locations of those sites have been altered. Those located on the present map have been fixed as near as possible from old plans showing features also marked on the present one.

For purposes of this report the drillholes have been renumbered, but the old reference and number is given in each case. Ferrar did not quote the logs; but for the sake of completeness it is thought desirable that they be included in this report. They are as follows:—

Drillhole No. 1. Hutton (1872), marked "A" on Hutton's sketch-plan—

Grey sandy clay	45 ft.	45 ft.
Hard grey calcareous sandstones	52 ft.	97 ft.
Green sandstone	71 ft.	168 ft.
Coal	7 ft.	175 ft
Total	175 ft.	

Drillhole No. 2: Hutton (1872), p. 117, and marked "B" on sketch-plan—

Grey sandy clay and surface beds	74 ft.	74 ft.
Calcareous sandstones, limestones, and calcareous partings	163 ft.	237 ft.
Greensands with calcareous bands and conglomerates	35 ft.	272 ft.
Coal	5 ft.	277 ft
Fireclay	5 ft.	282 ft.
Total	282 ft.	

Drillhole No. 3: Denniston (1877), No. 1 Hole of Denniston—

Soft clay	20 ft. 0 in.	20 ft. 0 in.
Soft sandstone or claystone..	25 ft. 0 in.	45 ft. 0 in.
Hard rock	51 ft. 6 in.	96 ft. 6 in.
Soft white stone	15 ft. 0 in.	111 ft. 6 in.
Soft green sandstone	14 ft. 0 in.	125 ft. 6 in.
Hard and soft green sandstone, boulders, and clay	14 ft. 0 in.	139 ft. 6 in.
Hard grey limestone	17 ft. 0 in.	156 ft. 6 in.
Conglomerate	10 ft. 0 in.	166 ft. 6 in.
Coal	4 ft. 6 in.	171 ft. 0 in.
Fireclay	2 ft. 6 in.	173 ft. 6 in.
Total	173 ft. 6 in.	

Drillhole No. 4: Denniston (1877), No. 2 Hole of Denniston—

Hard cement	6 ft. 8 in.	6 ft. 8 in.
Mixed brown clay and pebbles	17 ft. 1 in.	23 ft. 9 in.
White pipeclay and pebbles	28 ft. 3 in.	52 ft. 0 in.
Stiff green clay, oxidized	20 ft. 0 in.	72 ft. 0 in.
Hard brown clay	2 ft. 0 in.	74 ft. 0 in.
Hard grey limestone	11 ft. 3½ in.	85 ft. 3½ in.
Hard grey and green clay	3 ft. 9¾ in.	89 ft' 1¼ in.
Hard grey limestone	4 ft. 10¾ in.	94 ft. 0 in.
Grey and brown limestone	11 ft. 3¼ in.	105 ft. 3¼ in.
Hard grey limestone mixed with clay ..	26 ft. 0¼ in.	131 ft. 3½ in.
Hard brown sandy clay	1 ft. 10 in.	133 ft. 1½ in.
Free cutting reddish to brown limestone mixed with clay	3 ft. 6½ in.	136 ft. 8 in.
Hard brown clay	1 ft. 7 in.	138 ft. 3 in.
Total	138 ft. 3 in.	

Drillhole No. 5: Denniston (1877), No. 4 Hole of Denniston—

Strong yellow stone	30 ft. 0 in.	30 ft. 0 in.
Brown sandstone	0 ft. 6 in.	30 ft. 6 in.
Compact mass of chert imbedded in strong clay	13 ft. 4 in.	43 ft. 10 in.
Black marl	0 ft. 6 in.	44 ft. 4 in.
Stone, very hard	1 ft. 0 in.	45 ft. 4 in.
Drift gravel (loose)	6 ft. 3 in.	51 ft. 7 in.
Brown soft sandstone	3 ft. 0 in.	54 ft. 7 in.
Stone, very hard	1 ft. 8 in.	56 ft. 3 in.
Grey sandstone	8 ft. 6 in.	64 ft. 9 in.
Blue limestone, hard and fine-grained ..	17 ft. 7 in.	82 ft. 4 in.
Band of blue clay	0 ft. 4 in.	82 ft. 8 in.
Blue limestone, very hard	15 ft. 8 in.	98 ft. 4 in.
Blue clay parting	0 ft. 3 in.	98 ft. 7 in.
Blue and grey limestone	55 ft. 6 in.	154 ft. 1 in.
Clay partings and limestone	74 ft. 4 in.	228 ft. 5 in.
Coal, inferior, mixed with black clay coal and marl	3 ft. 4 in.	231 ft. 9 in.
Fireclay	14 ft. 0 in.	245 ft. 9 in.
Brown shale	0 ft. 11 in.	246 ft. 8 in.
Blue stone, trace of lime	4 ft. 5 in.	251 ft. 1 in.
Fireclay	2 ft. 4 in.	253 ft. 5 in.
Hard, white sandstone	3 ft. 8 in.	257 ft. 1 in.
Sandstone, coarse and dark	14 ft. 1 in.	271 ft. 2 in.
Blue stone, with shale bands	30 ft. 0 in.	301 ft. 2 in.
Coal, inferior (brown)	0 ft. 3 in.	301 ft. 5 in.
Brown shale	0 ft. 9 in.	302 ft. 2 in.
Blue stone, shale bands	18 ft. 0 in.	320 ft. 2 in.
Coal, good	0 ft. 3 in.	320 ft. 5 in.
Brown fireclay and coal	0 ft. 9 in.	321 ft. 2 in.
Blue stone and sandstone	117 ft. 0 in.	438 ft. 2 in.
Total	438 ft. 2 in.	

Drillhole No. 6: McKay (1884) and Hector (1894), Diamond Drill, hole No. 1. Also shown on Ferrar's maps (1925)—

Surface clay and Recent	66 ft.	66 ft.
Whangarei limestone	249 ft.	315 ft.
Marly greensands and Island Sandstone ..	186 ft.	501 ft.
Coal formation	48 ft.	549 ft.
Devonian	47 ft.	596 ft.
Total	596 ft.	

Drillhole No. 7 : McKay (1884) and Hector (1894), Diamond Drill, hole No. 2. Also shown on Ferrar's maps (1925)—

Surface clays and Recent	11 ft.	11 ft.
Blue clay, passing to Amuri limestone with flints	234 ft.	245 ft.
Whangarei limestone	208 ft.	453 ft.
Marly greensands and Island sandstone ..	193 ft.	646 ft.
Coal formation (1 ft. coal)	39 ft.	685 ft.
Devonian	4 ft.	689 ft.
Total	689 ft.	

Drillhole No. 8 : McKay (1884) and Hector (1894), Diamond Drill, hole No. 3. Also shown on Ferrar's maps (1925)—

Surface clays and Recent	46 ft.	46 ft.
Whangarei limestone	245 ft.	291 ft.
Coal formation (1 ft. 3 in. coal)	31 ft.	322 ft.
Devonian	1 ft. 8 in.	323 ft. 8 in.
Total	323 ft. 8 in.	

Drillhole No. 9 : McKay (1884) and Hector (1894), Diamond Drill, hole No. 4. Also shown on Ferrar's maps (1925)—

Surface clays and Recent	83 ft.	83 ft.
Marly greensands and Island sandstone ..	68 ft.	151 ft.
Coal formation (1 ft. coal)	17 ft. 6 in.	168 ft. 6 in.
Devonian	16 ft. 0 in.	184 ft. 6 in.
Total	184 ft. 6 in.	

Drillhole No. 10 (Mines Department file N. 12/18): Hole No. 1 sunk in 1928-29. This hole passed through 260 ft. of solid white limestone to a slate floor, no coal.

Drillhole No. 11 (Mines Department file N. 12/18): Hole No. 2, sunk 1928–29. This hole was 380 ft. deep, and passed through limestone, conglomerate, &c. The drill superintendent stated that the coal was at least 500 ft. deep at this point, and the plant could not reach it.

Drillhole No. 12 : (Mines Department file N. 12/18): Hole No. 3, sunk in 1928–29. The hole passed through 30 ft. of solid limestone near the surface, then through old sea-bed, presumably the marine greensand, to a total depth of 290 ft. A broken seam only was met at the bottom.

Drillhole No. 13 (Mines Department file N. 12/18): Hole No. 4, sunk in 1928–29. This bore reached to 90 ft. in a place where local authorities considered good coal would be met between 80 ft. and 90 ft. from the surface, but no defined seam was met, merely broken coal.

The last four holes have not previously been recorded in geological literature. In addition, the earliest reports indicate that several holes were sunk over the coalfield before working commenced, but no records or plans of them are available. Of the thirteen holes logged in this report, eleven were sunk beyond the main coalfield in attempts to locate extensions of the coal.

In the Mines Statement for 1898 it was stated that four holes were sunk in the swamp area west of the township, to depths of 60 ft. to 136 ft., and that irregular coal up to 5 ft. thick was encountered. Mr. Fleet pointed out to the writer the site of one of these, where he stated 4 ft. 6 in. of coal was met at 140 ft. from the surface, and its location has been marked on the plan as No. 14. He stated that, several chains to the north-west, a second hole had shown the coal to thicken to 5 ft.

STRATIGRAPHY

Certain problems are introduced in the area which would require lengthy discussion in so far as the complete stratigraphic column is concerned, but as such discussion would in no way affect the distribution of possible coal-measures a brief statement of stratigraphic relations has been considered sufficient for this report.

The coal-measures themselves form the basal members of the Whangarei Series of mid-Tertiary age, and rest unconformably on rocks of three older series. The oldest of the basement rocks are Mesozoic or older, and comprise greywackes and argillites of the Waipapa Series. The thickest portions of the coal-seams rest on these rocks. Next come a series of argillites and well-consolidated shales and claystones of the Kaeo Series (not previously recognized), which underlie the coal-measures in the main road cutting opposite the quarry a mile south of Kawakawa Township. They are visible only for a few chains and are faulted against the Waipapa rocks as a narrow strip. The youngest beds below the coal members are limestones, shales, sandstones, &c., belonging to the Onerahi Series of Eocene age.

The greywackes of the Waipapa Series are exposed in the township area and south along the main road for a mile. They are overlain by Whangarei strata, the contact trending south-east from a short distance west of the railway-station to the main road at the quarry a mile south of the town, thence across the road for three-quarters of a mile till it crosses Waiomio Stream. The contact then continues south-east to the southern end of the Waiomio East basin, a total distance of three and a half miles. The beds of the Whangarei Series form a strip up to a mile wide, and dip south-west on a plunging greywacke surface, which, under the former beds, passes beneath, or is faulted against, the rocks of the Onerahi Series which thus form the basement for the Whangarei beds along their south-west portion, and come to the surface exclusively in that direction.

The small strip of rocks referred to as the Kaeo Series is unique in the area under discussion, and clearly does not belong to either the Waipapa or Onerahi sediments. It closely resembles rocks in other parts of North Auckland that have been included in the Kaeo Series by Bell and Clarke (*loc. cit.*). It has been classed accordingly and not as the Onerahi Series as defined by Ferrar (1925).

The Onerahi Series are now generally thought to be Eocene, and what evidence of their age is available from other parts suggests they belong to the Bortonian stage. Their structure is usually complex, due to acute folding, and fossils are comparatively scarce. Their stratigraphic sequence, and consequently correlations, are, therefore, very incompletely known, and mapping has been largely determined by lithologic comparisons. The hydraulic limestone facies, which is found in the Kawakawa district, both in the Waiomio East and Waiharakeke basins, is usually regarded as belonging to the true Onerahi Series, but there are extensive deposits of shales, mudstones, sandstones, and claystones of various colours, with, in places, associated siliceous bands whose age is unknown. Such beds outcrop over much of the area south-west of the Whangarei rocks in the Kawakawa area and extend west and south-west for many miles. It is thought that certain members of these do not belong to the Onerahi group, but are older, probably Upper Cretaceous, though it is at this stage impossible to map them as a separate unit, and the previous policy of including them with the Onerahi Series has been followed in this report.

The Whangarei Series was laid down during the Miocene, when a landmass of a certain amount of relief was slowly submerged. In the inland basins and coastal estuaries, where suitable vegetation was available—and this seems to have been in and adjacent to the terrain of true Waipapa beds—coal-measures accumulated during the early stages, and these always occupy the extreme basal portion of the Whangarei beds in the area. As the sea broke in, with continued submergence, marine sandstones accumulated and later these gave place to calcareous members, which now occur as

white crystalline limestone where other sediments were at that time lacking. This gives the general sequence of the Whangarei beds in the Kawakawa and Waiomio areas.

Holes sunk in the coalfield area reveal that the coal-measures lie directly on slates, apparently of the Waipapa Series. In the road cutting near the quarry, one mile south from Kawakawa Township, the base of the series is seen to lie unconformably on beds of the Kaeo Series. From the base up the sequence is as follows: 1 ft. to 18 in. of well-cemented quartz grit, 6 in. to 1 ft. or carbonaceous shale, 1 ft. of black, silicified shales and quartz sandstone, then light grey glauconitic sandstone. The coal-measures are only 6 ft. thick at this place. Hole No. 6 gives a typical section in the coalfield area. The greensands appear to grade laterally into a hard, calcareous, green sandstone and the white limestone of the Waiomio area into hard grey limestone where it contains sedimentary impurities. Near its base at the extreme south-east margin of the series the base of the limestone contains quartz grit and overlies coarse grit conglomerate with pebbles of greywacke up to 2 in. in diameter, which appear to separate the limestone from the greywacke basement. No outcrops of coal-measures were found in that section.

As a general rule the coal-measures appear to have thickened towards the south-west, though the actual coal-seams thinned in that direction. This is probably due to larger basins having existed in the more easily eroded area of Onerahi sediments, combined with the fact that the dense vegetation yielding the material for the coal at the same time was confined to the greywacke land. The greatest total thickness of coal appears to have been about 16 ft. and the greatest average thickness to have been along the north-east and north portions of the worked-out area.

The coal-measures are exposed also in the gully 25 chains south-west of the hospital, where shallow coal was taken out a few years ago. Silicified sandstones, carbonaceous sandstones, and fireclay are the rocks exposed; but, as the floor is black, silicified sandstone, the coal seems to have been removed from a false bottom only. Until the basement rocks are reached there is still a chance of another seam below the silicified sandstone. In the gully near Moody's outcrop a sequence downwards from conglomeratic greensand through 1 ft. of carbonaceous sandstone, 6 in. to 1 ft. of poor coal, 1 ft. of carbonaceous sandstone, 5 ft. to 6 ft. of fireclay and black shale, and light-grey sandstone, mostly silicified, is exposed not far above an outcrop of greywacke. In recent years drives went from here as far as the old workings. Other similar outcrops are to be seen in the vicinity of McLeod's outcrop, east of the main road south.

The greensands are well exposed in the gully south-west of the hospital, down-stream from the coal-measures. They outcrop also along the main road south of the exposure of the coal-measures near the quarry, for a distance of over half a mile, and within that distance are seen in places to grade into calcareous sandstone. In the Waiomio East basin the crystalline limestone forms prominent outcrops similar to those well known in the Waro area near Hikurangi. West of Waiomio West Stream no outcrops of white limestone are to be seen, as it apparently grades into a dark-grey limestone in that direction; but rock described as Whangarei limestone was met in some of the drillholes in the Kawakawa area.

In the cutting near the top of the hill, half a mile north of the Waiomio corner, an unconformity in the Tertiary beds is exposed. A red grit unconformably overlies the marine sandstones of the Whangarei Series. Above it again at the top of the hill are clays with fragments of siliceous

material probably derived from Onerahi rocks. The age of the last-mentioned beds is probably Pliocene or younger, and the age of the red grits is unknown, but neither is a mappable unit and both are included within the area of Whangarei sediments.

Sandstones, shales, and claystones outcropping in a gully near No. 2 drillhole are thought to belong to the Onerahi Series, or older beds, though mapped with the Whangarei sandstones and limestones by Ferrar. Outcrops of Whangarei crystalline limestone there appear to be residual blocks resting on, rather than underlying, the accompanying beds exposed in the gully. In the Waiomio area Ferrar described similar beds as overlying the limestone, but the writer found vertical red shales, similar to those in the gully last mentioned, between two of the large limestone blocks ten chains south of the caves. Large-scale faulting is also attested by an extremely coarse fault breccia exposed in a cutting on the main road 15 chains north of the Waiomio corner, and again 15 chains to 20 chains farther north. At the latter place there are also small low-angle thrust faults intersecting the Whangarei sandstones and overlying red grits. The description from drillhole No. 7 of beds resembling the Onerahi sediments as overlying the Whangarei limestone also suggests the possibility of the presence of large-scale overthrust faulting, but there are no outcrops of the beds concerned in that area, and positive field evidence of the nature and extent of such faulting is lacking. Consequently detailed mapping along the north-west margin of the Whangarei beds is impossible.

The logs of drillhole No. 6 and the shaft between it and the railway-station suggest that the Pleistocene Purua beds may be more widely distributed than indicated by Ferrar's mapping. Much of the ridge south-west of the old workings may belong to this series.

POSSIBLE EXISTING COAL RESOURCES

The writer was given access to the old Kawakawa Mine plan, brought up to date to 1894. The limits of working as shown on the plan have been marked on the map accompanying this report. It agrees reasonably well with the plan published by Hector (1894), in which the thicknesses of coal at various points in the peripheral workings were shown. The strike of the coal on the average was north-west, and the dip south-west, swinging to north-west at the north-end. Towards the dip it thinned throughout most of the mine, as also towards the south, and in both of these directions mining extended as far as was payable. Extra coal was taken out from the surface south-west of the hospital, and underground from the direction of Moody's outcrop, but holes Nos. 8, 9, 10, and 11, and the evidence from the outcrop on the main road near the quarry, suggest that there is no possibility of an extension of the worked field to the south.

McKay (1884) considered that the Onerahi beds overlay the Whangarei Series, and that the coal-measures would consequently be found at greatly increased depths to the west, but that interpretation and its deductions must be discarded. At the same time drillholes 6 and 7 prove the consistent thinning in that direction as indicated also in the actual workings.

In the north there appears to be conflicting evidence in the data available, and it is in this direction that there has been most interest shown by those locally concerned with the locating of a new coalfield. The old workings in this direction extended towards the swamp covering much of the flat through which flow the Ramarama and Ngapipito streams. The dip of the coal seems to swing gradually round here until it dips north-west. Numerous reasons appear to have been given for the cessation of work in this section.

Hector (1894) stated that the coal was cut off to the north by a "master fault," shown in the 1867 report. There does not appear to be such a report, unless he refers to Hutton's (1872) report, where, as mentioned previously, it is believed that a mistake in direction was made in saying that the coal was worked "N. by E." instead of "S. by E.", in which direction a fault was encountered and is illustrated on the map accompanying that report. The area under consideration was certainly not being worked as early as 1867. Ferrar (1925) stated that to the north "an inrush of water and gravel took place, and the seam came to an end against what was thought to be a fault. More probably, however, the workings reached the alluvial deposits of the stream that flowed down the Kawakawa Valley in Pleistocene times."

There appears to have been flooding in the north, but to what extent is unknown. The depth of gravels filling the old Kawakawa valley is unknown, and drillhole No. 13, which met broken coal at 90 ft apparently did not show the gravels to extend down to the depth necessary for them to have broken into the old workings. Local residents state that there was a good face of coal in the north when the mine closed, and are of the opinion that the mine was closed by the directors when the Hikurangi Mine commenced work. Mr. Fleet, whose father worked in the mine, and who was a boy and in the habit of going underground at the time that work ceased in that section, states that there was a face of 7 ft. of coal at the time of closing.

Drillhole No. 5 showed 3 ft. 4 in. of inferior coal at a depth of approximately 230 ft. from the surface, with seams a few inches thick for some distance below. A broken seam was met in No. 12, and also in No. 13. No. 14, at a site intermediate between the last two, gave 4 ft. 6 in. of coal, which was reported to have thickened to 5 ft. in another hole a few chains to the north-west. These are two of four holes mentioned in the Mines Statement for 1898, in which it is stated that the coal was irregular under the swamp, and not thought to be payable.

Thus the balance of evidence for the extension of coal under the swamp is unfavourable, another objection adduced by several writers being that the ground would be wet and treacherous. That, of course, would depend on the nature and thickness of the overlying strata. There is thus a certain amount of conflicting evidence, and the writer is of the opinion that, to settle the matter, a carefully cored hole between Nos. 13 and 14, at a site marked "A" on the accompanying map, would give the maximum amount of information.

The other possibility of locating a new coalfield appears to be in the upper Waiomio East basin, where drilling was previously recommended by both McKay (1898) and Ferrar (1925). There is no direct evidence for the presence of coal in this area, as no beds belonging to the coal-measures have been found, and, indeed, at the southern margin of the basin the limestone seems to be separated from the greywacke by conglomerate only, both the greensands and the coal-measures being absent. An outcrop of brown sandstone, probably belonging to the marine sandstones beneath the limestone and above the coal-measures, was found in the gully north-east of the Waiomio Caves. This suggests that the same sequence as found farther north-west towards Kawakawa is here present, though to what extent the full sequence is developed is not known, and there is no way of determining except by drilling. Ferrar (1925) showed a suggested cross section of the Waiomio Valley, in which he postulated a thickening of the marine sandstone beneath the limestone in the centre of the valley, with possible coal-measures at the base. The evidence from the Kawakawa area

is that the coal was thickest nearest to the greywacke on the east margin and it is reasonable to expect that in the Waiomio the same relation would hold if coal were present. It is therefore thought that drilling to prospect for coal should preferably explore the eastern half. Suggested sites for drilling have accordingly been marked alternatively at "B" and "C." A hole sunk at either site should prove conclusively whether coal-measures are present in this basin and whether further prospecting would be warranted.

It was mentioned previously that claystones, thought by Ferrar to overlie the limestone, were found by the writer standing vertical between two large limestone blocks. This suggests faulting, which would influence strongly the working of any coal located in the Waiomio area. It is therefore suggested that if coal be located at either of the two sites selected, a further bore be sunk at "D" to test the presence of the possible fault.

REFERENCES

HECTOR, J. (1866): "Coal Deposits of New Zealand."

HUTTON, F. W. (1872): "Report on the Coal Mines in the Province of Auckland." *Repts. Geol. Explor. 1871–72, No. 7*, pp. 114–6.

HECTOR, J. (1877): "Kawakawa, Bay of Islands." *Repts. Geol. Explor., 1876–77, No. 10*, p. XIII.

DENNISTON, R. B. (1877): "Summary Report of Coal Explorations, Auckland District." *Ibid.*, pp. 135–8.

COX, S. H. (1882). "On Certain Points connected with the Geology of the Auckland District." *Repts. Geol. Explor., 1881, No. 14*, pp. 92–4.

MCKAY, A. (1884): "On the Geology of the Coal-bearing Area between Whangarei and Hokianga." *Repts. Geol. Explor., 1883–84, No. 16*, pp. 110–34.

HECTOR, J. (1894): "Northern Auckland." *Repts. Geol. Explor., 1892–93, No. 22*, pp. X.–XV.

MCKAY, A. (1898): "Report on Further Prospecting for Coal at Kawakawa, Bay of Islands County." C.–9, pp. 5–6.

BELL, J. M., and CLARKE, E. DE C. (1909): "The Geology of the Whangaroa Subdivision." *N.Z.G.S. Bull. 8.*

FERRAR, H. T. (1925): "The Geology of the Whangarei–Bay of Islands Subdivision." *N.Z.G.S. Bull. 27.*

THE CONSTITUTION OF TARANAKI IRONSAND

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Summary

Work on the selective action of reagents on ironsand is reviewed and extended. It is shown that the chemical evidence supports the postulate of vanadium containing titano-magnetite being the chief mineral—not separate titanium and vanadium minerals.

IN a paper by C. O. Hutton (this *Journal* (1945), *26* (*Sec. B*), 6, 291), the writer stressed the relative absence of pure titanium minerals, and showed that the titanium was present as a titanomagnetite (ferro-magnetic) and titano-hæmatite (para-magnetic). Thus the strongly magnetic portion contained Ti and Fe in one mineral of spinel type. He also stated that he believed the vanadium associated with the ore to occur in the same spinel structure. In this paper we put forward purely chemical evidence in favour of a similar conclusion, evidence which has accumulated during a study of methods of extraction of vanadium from ironsand. So many promising methods based on differential attack of the mineral have failed to separate titanium and vanadium from ironsand that the writers have been forced to the conclusion that no method will succeed unless it is based on the chemical change and attack of the whole mineral. All our work was carried out on the magnetically separated ore, which thus contained titanomagnetite rather than titanohæmatite. Through the courtesy of the Dominion Laboratory we had access to a very fine series of samples taken for a survey of iron resources, and although many estimations of vanadium were done on individual samples of that series, the main work described hereafter was done on a Patea composite sample which represents the very large deposits occurring in that locality.

(*a*) *Fusion Methods.*—One of us (A. D. M.) with H. S. Gibbs has published a list of fusion methods and their results (this *Journal* (1938), *19*, 523). The most promising of these fusions was a fusion with calcium oxide and calcium chloride, resulting in good extraction of vanadium, but a difficult separation from titanium. In this paper we add two new types of fusion. Sodium carbonate or sodium and potassium carbonate fusions were found to be satisfactory with very low proportions of carbonate if a trace of sulphur, sodium sulphide, or sodium sulphite was added. For analytical purposes two fusions are necessary. In our work we estimated the vanadium separately in the two fusions, and in some cases did a third fusion and proved a blank. After each fusion the product was leached with hot water and the vanadium estimated by the hydrogen peroxide and the phosphotungstic (Vinogradov) methods. Results by these two methods agreed very closely. The amount of titanium leached is negligible—this was proved by the agreement of hydrogen peroxide results with and without the addition of fluoride ion, and by agreement with the phosphotungstic method, which is unaffected by the presence of titanium. In judging the tint by hydrogen peroxide, Nessler glasses were used ; in the phosphotungstic method the pale-yellow tint was estimated in a Lovibond tintometer using a calibration curve and a special long cell for intensification of the pale colour. With 1 g. of ironsand, 1 g. of sodium carbonate, and 0·05 g. of sodium sulphite, the first fusions (one hour and a half) yielded 3·8 and 3·7 mg. of V_2O_5, the second, 1·1 mg., and the third a trace certainly less than 0·2 mg. and reported as 0·1. In

this part of the work we received valuable assistance from Mr. E. P. White. This offers a possible economic method of extraction of vanadium. A recrystallization of the solution containing sodium carbonate and sodium vanadate concentrates vanadium in the last fraction to crystallize. Titanium remains as insoluble sodium titanate with the iron. When leached with N-H_2SO_4 the titanium passes into solution along with very little iron, thus fully separating the vanadium with almost complete separation of titanium and iron.

The second fusion of interest is a repetition of Kjellberg's fluoride method in so far as the details given by Wylie (this *Journal* (1938), *19*, 572) enabled it to be repeated. This is a calcium fluoride fusion with sulphurous acid extraction. Monro and Gibbs (*loc. cit.*) have previously reported a fluorspur fusion, but with the acids tried the results were inferior to the results obtained by CaO——$CaCl_2$ fusions. In the Kjellberg fusions fine ground ironsand was mixed with CaF_2 and heated with the blow-pipe burner for half an hour. The resulting hard button was cooled, crushed, transferred to a beaker with 50 ml. saturated H_2SO_3, and allowed to stand for twenty-four hours. The solution was then filtered, 3 ml. of HCl added, and boiled. Finally the solution was oxidized by boiling with 3 ml. of HNO_3, and the vanadium estimated by H_2O_2. Although Kjellberg claimed 80 per cent. extraction of vanadium, this is not equalled in the following results and a separation from Ti and Fe is not wholly achieved. (Fuming with H_2SO_4 was, of course, necessary before estimation of Ti by H_2O_2.)

TABLE I.—FLUORIDE FUSIONS WITH EXTRACTION BY H_2SO_3

(Each fusion with 1 g. of ironsand)

—	Weight of CaF_2, in Grams.	Weight of V recovered, in Grams.	Percentage of V recovered.	Weight of Titanium recovered, in Grams.	Weight of Iron recovered, in Grams.
(*a*)	0·5	0·0018	64	0·0006	0·0009
(*b*)	1	0·0019	68	0·0019	0·0045
(*c*)	2	0·0020	71	0·0050	0·0064
(*d*)	4	0·0019	68	0·0038	0·0108

(*a*), (*b*), and (*c*) are averages of two experiments; (*b*) and (*c*) are total recoveries from two fusions each, the second fusion giving small V recoveries of the order of 0·0002.

In two further fusions, Na_3AlF_6 was substituted for CaF_2. A small correction was necessary for Ti and Fe present in the cryolite.

TABLE II

Weight of Na_3AlF_6, in Grams.	Weight of V recovered, in Grams.	Percentage of V recovered.	Weight of Ti recovered, in Grams.	Weight of Fe recovered, in Grams.
1	0·0020	72	0·0013	0·0008
2	0·0021	76	0·0024	0·0005

In this modification the recoveries of V are higher without increased percentages of titanium and iron.

It will be seen from these accounts of fusion methods that they do enable V to be separated. But they are based on the complete attack of the whole crystal, not on the selective solution of one constituent.

(*b*) *Action of Aqueous Solutions on Ironsand.* The only aqueous solutions which are known to act on ironsand are the mineral acids. Alkaline solutions, sodium hydroxide, sodium sulphide, &c., have no action. Of the acids, HCl is the best known solvent, attacking ironsand slowly even at room temperature; sulphuric acid is slower, and nitric acid has very little action. Oxidizing and reducing-acid mixtures have been tried, HCl with $SnCl_2$, H_2SO_4 with H_2SO_3, and H_2SO_4, with $(NH_4)_2S_2O_8$. If there are two or more minerals in the magnetically separated sand, it is to be expected that one will dissolve faster than the others. Hence even if total extraction shows no change in V : Ti : Fe ratios, partial extraction should show a change. As no such change has been found, it is inferred that there are not two minerals, but that the space lattice is broken down layer by layer with preservation of substantially the same ratio in both solution and residue throughout. The ironsand composite contained 56·6 per cent. Fe, 4·67 per cent. Ti, and 0·28 per cent. V. Calculated from these figures is the relative atomic abundance, Fe : Ti : V as 180 : 18 : 1. In the following table the percentage extraction (calculated on 100 g. ironsand) is given, together with the relative atomic abundance for different fractions.

TABLE III

Reagent.	Percentage			Ratio.
	V.	Ti.	Fe	V Ti Fe.
HCl exhaustive (two experiments)—				
Solution	0·27	4·96	57·4	1 : 20 : 190
Residue	0·01	0·28	0·70	1 : 30 : 60
HCl partial—				
First extract	0·10	1·36	19·5	1 : 15 : 180
Second extract	0·09	1·45	17·5	1 : 17 : 180
Residue	0·11	2·06	20·2	1 : 20 : 170
HCl + $SnCl_2$ partial—				
(*a*) 0·02 g. per millilitre HCl	0·15	1·70	26·2	1 : 12 : 160
(*b*) 0·03 g. per millilitre HCl . . .	0·08	1·69	21·8	1 : 15 : 250
(*c*) 0·15 g. per millilitre HCl	0·07	1·09	22·0	1 : 17 : 290
HCl + $(NH_4)_2S_2O_8$ 0·15 g. per millilitre HCl .	0·09	1·29	18·5	1 : 15 : 190
H_2SO_4 exhaustive (three experiments)—				
Solution	0·22	4·68	50·5	1 : 23 : 210
Residue	0·05	0·78	7·2	1 : 17 : 130
H_2SO_4 partial—				
First extract	0·13	2·88	29·0	1 : 23 : 200
Second extract	0·10	1·76	19·3	1 : 19 : 180
Residue	0·05	0·65	9·4	1 : 14 : 170
H_2SO_4 + H_2SO_3—				
1 ml. sat. H_2SO_3 per millilitre H_2SO_4	0·15	2·98	32·1	1 : 21 : 200
2 ml. sat. H_2SO_3 per millilitre H_2SO_4	0·13	2·51	28·0	1 : 21 : 200
4 ml. sat. H_2SO_3 per millilitre H_2SO_4 ..	0·09	1·76	19·9	1 : 21 : 200
H_2SO_4 + $(NH_4)_2S_2O_8$—				
0·1 g. per millilitre H_2SO_4	0·17	3·05	32·5	1 : 19 : 170
0·2 g. per millilitre H_2SO_4	0·18	3·32	37·1	1 : 20 : 190
0·4 g. per millilitre H_2SO_4	0·18	3·46	35·4	1 : 20 : 180
HNO_3 (two experiments): Solution	0·04	0·78	6·3	1 : 21 : 140

It will be seen that the ratios of the three elements differ but slightly throughout, the apparent exception, the residue after HCl extraction, being on so small a quantity that it has little significance. It seems that stannous chloride has a slight selective influence on the iron, but otherwise the substantial constancy of the ratios is the main feature.

(*c*) *Oxidation by Air.*—Roasted in air, ironsand gains approximately 1·6 per cent. in weight, presumably from the breakdown of the spinel type crystal

to a titanohæmatite type. Complete oxidation to Fe_2O_3 should involve an increase of 3·4 per cent. in weight. As this means an altered form of crystal, the action of HCl and H_2SO_4 was tried on the roasted sand with the following results :—

TABLE IV

Reagent.	Percentage.			Ratio.
	V.	Ti.	Fe.	V : Ti : Fe.
HCl exhaustive (three experiments)—				
Solution	0·18	3·11	41·4	1 : 18 : 210
Residue	0·10	1·76	14·0	1 : 19 : 130
HCl partial—				
First extraction	0·02	0·22	5·4	1 : 12 : 250
Second extraction	0·01	0·26	3·6	1 : 28 : 330
Residue	0·26	4·32	44·8	1 : 18 : 160
H_2SO_4 exhaustive (three experiments)—				
Solution	0·18	3·95	42·5	1 : 23 : 220
Residue	0·09	1·17	14·0	1 : 14 : 140
H_2SO_4 partial—				
First extraction	0·02	0·22	4·4	1 : 12 : 200
Second extraction	0·08	1·42	15·8	1 : 19 : 180
Residue	0·21	3·29	35·5	1 : 17 : 150
HNO_3 exhaustive : Solution	Nil	0·02	1·3	..

Solution in acids is but little affected in ratio by oxidation, although there is some tendency for the oxidized iron to dissolve to a greater extent than the Ti or V. The rate of solution is appreciably less than before oxidation and the insoluble residue greater. The disintegrated crystal layers should offer more chance of a selective reagent extracting vanadium. Hence the action of 20 per cent. sodium hydroxide was tried on the roasted sand. About 1 per cent. of the vanadium but no Ti or Fe was extracted. This is encouraging, and it is hoped to do more experimentation on this point.

(d) Volatilization of Chlorides.—The ease with which $VOCl_3$ forms and can be vaporized suggested a possible method of separation. Jannach and Harwood (*J. Pr. Chem.* (1909), *80*, 127) found that a separation of V and Fe could be obtained, and Grigg (N.Z. Univ. Thesis, 1943) separated V and Fe from a mixture of V_2O_5 and Fe_2O_3 by heating in carbon tetrachloride vapour, although a part of the iron sublimed as Fe_2Cl_6. From 0·0218 g. of V with 0·14 g. Fe, Grigg recovered in the distillate 0·0216 g. of V with 0·066 g. Fe. Trials were made with 1 g. of finely ground ironsand by leading pure dry CCl_4 vapour over it. On heating, a vigorous reaction took place and was continued until action appeared to have stopped. The reaction products were collected in well-cooled dilute hydrochloric acid and yielded the following results :—

TABLE V.—VOLATILIZATION OF IRONSAND WITH CCl_4 VAPOUR

—	Percentage of Sand volatilized.	Percentage.			Ratio.
		V.	Ti.	Fe.	V : Ti : Te.
1	16·4	0·02	0·32	6·7	1 : 17 : 310
2	31·8	0·07	1·68	24·0	1 : 26 : 310
3	39·1	0·11	2·02	29·5	1 : 20 : 240
4	49·3	0·11	2·38	35·3	1 : 23 : 290
5	57·1	0·14	3·38	35·9	1 : 26 : 230
6	57·3	0·13	2·54	42·6	1 : 21 : 300
7	48·3	0·12	2·66	33·3	1 : 23 : 250
7 (residue)	..	0·14	1·93	22·3	1 : 15 : 150

It will be seen that there is slight separation only, the vanadium appearing in the volatile portion in some runs in less ratio than in the original sand. Apart from the slight preferential volatility of the iron (which appears in runs 3, 5, and 7 to be very slight), one conceives of this process as taking place in the space lattice layer by layer, the proportions in the distillate being substantially the same as the proportions in each layer.

We conclude that the results of these various methods of attack are consistent only with the single space lattice theory of the structure of iron-sand. If we accept the composition of the mineral as containing V : Ti : Fe :: 1 : 18 : 180 approximately, it means that in every 200 of the metal positions of a spinel 1 is occupied by V, 18 by Ti, and the remainder by Fe. Although it is not proper to think of such a structure as molecules, we imagine individual units (the unit cell of a spinel is eight such units) to consist of either Fe_3O_4 or Fe_2TiO_4 or Fe_2VO_4. This raises certain questions of valency and of ionic radii. Goldschmidt gave the ionic radii as follows (*Trans. Farad. Soc.* (1929), *25*, 282): Fe^{++} 0·79Å; Fe^{+++} 0·67Å; Ti^{++++} 0·64Å V^{+++++} ca 0·4Å; V^{++++} 0·61Å; V^{+++} 0·65Å. The replacement of Fe^{+++} by Ti^{++++} would cause little lattice distortion. Replacement by V^{+++++} is chemically improbable and crystallographically would cause much distortion. Replacement by V^{+++} would cause little distortion, but is improbable in a system containing Fe^{+++}. Although replacement by V^{++++} involves a greater change in radius, it has the advantage that Fe^{++} and Fe^{+++} can co-exist with V^{++++}. A large proportionate replacement might mean crystal distortion, but the postulate of 1 in 200 replacement means a very small overall change in size. In fact, the small percentage of vanadium in ironsand may be the limit of replacement that the lattice can tolerate.

STUDIES ON PERLOLINE

PART II.—PERLOLIDINE AND SOME FLUORESCENT DERIVATIVES OF PERLOLINE

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Summary

Perlolidine was prepared by oxidation of perloline using permanganate and ferricyanide methods.

The formula of perlolidine is given as $C_{25}H_{18}O_2N_4$, but this may be subject to revision. It has a m.p. 326°c.

The hydrochloride, B. 2 HCl.2H_2O, does not melt at 350°c.

Perlolidine shows phenolic properties and in certain ways has similarities to harmol.

Many degradation processes on perloline lead to perlolidine. The nitrogen nucleus of perloline appears to be retained in perlolidine.

Oxidation products of perloline were prepared which on exposure to bright sunlight gave difficultly soluble compounds which were non-alkaloidal and dissolved in concentrated acids with intense colour and fluorescence.

GRIMMETT and Waters(1) isolated from rye-grass extracts "alkaloid C," now named perlolidine. In the course of investigations on perloline it was found that perlolidine was obtained as an intermediate product of mild oxidation, and many perloline derivatives gave perlolidine under similar conditions. It is formed on oxidation of perloline by permanganate in acid or alkaline solutions, by acid dichromate, by alkaline ferricyanide, and by perchloric acid. It is formed on oxidation of methylperloline, demethylated perloline, acetylperloline, the alcohol and aldehyde condensation products, and some other materials. Perlolidine is rather easily oxidized, and is an intermediate stage in these oxidations. Under special conditions it can be obtained in about 30 per cent. yield by oxidation.

Part I(2) of this publication contains evidence of perlolidine being formed also under conditions other than oxidation. It results in small yield by thermal degradation—*e.g.*, in N-methyl determinations—of most perloline derivatives after they have been demethylated. It is formed in appreciable amount by heating demethylated perloline with alkali, or by cold lead tetraacetate oxidation of this material. It also results from selenium dehydrogenation of perloline. As perlolidine appears to contain the major part of the perloline nucleus, including all the nitrogen atoms, and as so many degradation processes on perloline lead to perlolidine, it is felt that further study of this base would contribute largely to the elucidation of the structure of perloline.

Perlolidine base has a probable formula $C_{25}H_{18}O_2N_4$ and a m.p. 323–326°c. It is insoluble in water, and very slightly soluble in organic solvents, forming colourless solutions with a dull-blue fluorescence. The hydrochloride, B. 2 HCl. 2H_2O, does not melt at 350°c, and is soluble in water to a colourless solution with intense blue-violet fluorescence. Perlolidine has phenolic properties—*e.g.*, solubility in sodium hydroxide, and precipitation from this solution by carbon dioxide. It is a typical alkaloid. It contains no methoxy, ester, or N-methyl groups, and is unaltered by nitrous acid. From the

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beginning of this work it was recognized that perlolidine showed marked similarity in properties to harmol, the demethylated base from harmine. Harmol melts at 320°c.(3), 321°c.(4); and 320°c. was found for a sample prepared from harmine. Harmol hydrochloride, B. HCl . $\frac{1}{2}H_2O$, is stable to 350°c.(3). These materials showed depressions on admixture with the corresponding perlolidine ones. Harmol has similar phenolic and acidic properties to perlolidine, and the same colour of fluorescence, but the fluorescence of harmol (and harmine) is much less intense. Harmol has the formula $C_{12}H_{10}ON_2$ approximately half that of perlolidine, for which the larger formula appears to be justified by analytical data. Perlolidine appears to contain a similar structural unit. Other precise observations on the fluorescence and absorption spectra of perlolidine and harmol will be dealt with in a further Part.

Remarkable materials resulted when a " nitro " derivative of perloline or an intermediate product in perchloric acid oxidation of perloline, both alkaloidal bodies, were exposed to sunlight in acid solution. Materials which were remarkably insoluble in solvents, and non-alkaloidal, were formed in small yields. Solutions, for example, in concentrated acids were intensely coloured and showed intense fluorescence. The solids were dark materials, not melting at 350°c. Some superficial similarity to porphyrins was not supported by spectroscopic studies.

EXPERIMENTAL

Perlolidine

Oxidations forming Perlolidine.—Many oxidation methods give perlolidine in small yield as an intermediate product. In each case perlolidine was isolated in small yield and its identity proved by microchemical reactions and properties. Perloline in a water - sulphuric-acetic acid mixture containing a trace of nitrate, heated until fumes appeared, gave a trace of perlolidine. Oxidation by permanganate in cold acetic-sulphuric acid solution or in hot neutral or acid solutions gave yields of about 1 per cent. In dilute alkaline solution and excess permanganate only traces of the base were detectable as the oxidation was carried beyond the perlolidine stage. By the use of less permanganate, yields were increased (see " Preparation of Perlolidine "). In more concentrated solutions of perloline, oxidation in carbonate solution gave a strong indole-like odour, like that formed during peroxide oxidation, and the manganese dioxide contained some plate clusters, apparently the " peroxide oxidation product " (see Part I). 33 mg. of perloline oxidized in carbonate solution with permanganate was acidified, and distilled in the Kuhn-Roth apparatus. Only a trace of volatile acid was formed and no perlolidine. 19·45 mg. of perloline were refluxed for one and a half hours with 5 N chromic-sulphuric acid mixture according to the Kuhn-Roth procedure and only a trace of volatile acid was found. Traces of perlolidine were identified from this oxidation. Alkaline chromate was without action on perloline.

Preparation of Perlolidine by the Alkaline Permanganate Method.—Perloline was oxidized with permanganate added in small amounts at a time to a hot, very dilute solution made alkaline with carbonate. The oxidation was carried out in volumes of about a litre at a time, until tests showed that only a trace of perloline remained. This was usually at a stage slightly before a pink colour of permanganate persisted. In one case, 1,160 mg. of perloline hydrochloride in 10 litres of water were used, in another 997 mg. of hydrochloride in 10 litres. Manganese dioxide was filtered off, a few drops of sodium hydroxide added, and the solutions extracted twice with a little chloroform, whereby most of the perloline, but only a little

perlolidine, was extracted. From the total oxidation about 90 mg. of perloline were recovered unoxidized. The solution was then acidified with hydrochloric acid, when the characteristic blue fluorescence appeared, and the combined extracts were evaporated almost to dryness under low pressure. Salts were removed by addition of much alcohol, filtration, concentration of alcoholic extracts to dryness, and a repetition of the alcohol extraction. The crude perlolidine hydrochloride thus obtained was dissolved in water and the base precipitated from fairly concentrated solution by sodium carbonate or ammonia diffusion, and washed with a little water. Yields were 250 mg. and 204 mg. respectively of perlolidine base, of m.p. 304–315°c. As an alternative method of isolation, extraction from carbonate solution by chloroform, ether, or ethyl acetate was used; in each case a laborious number of extractions (twenty or so) was required to remove the alkaloid fairly completely. The base was considerably easier to purify when extracted this way.

The crude base was purified by molecular distillation of 0·01 mm. 327 mg. of crude (discoloured) base gave 169 mg. of sublimate, the rest remaining as a dark charred material, obviously from decomposition. The sublimate, which had acquired a slight yellow colour and a few specks of carbonized material, was recrystallized from hot alcohol, giving 132 mg. of colourless needles of perlolidine base, m.p. 323–326°c.

Preparation by the Ferricyanide Method.—500 mg. of perloline hydrochloride were dissolved in about 1,000 ml. of water. 10 g. of potassium ferricyanide and 50 g. of tertiary potassium phosphate were added to the hot solution, which was kept boiling for about fifty minutes. After adding 5 g. of sodium hydroxide, the solution was boiled for another ten minutes, cooled, and filtered off from a brown precipitate insoluble in water. This solution, if shaken into chloroform, showed no trace of perloline. After acidifying slightly with hydrochloric acid, the solution was again made alkaline with carbonate and extracted with ten lots of 200 ml. of chloroform. The base was shaken out twice from chloroform into a very dilute solution of hydrochloric acid, the total volume not exceeding 40 ml. Perlolidine was precipitated from the acid solution by addition of a little carbonate. After filtering, the precipitate was dried, giving a yield of crude perlolidine amounting to 135 mg. The base was again dissolved in 15 ml. of very dilute hydrochloric acid, and the base precipitated by ammonia diffusion, which process was repeated. The base was slightly discoloured, m.p. 323–327°c., with some darkening before melting. Recrystallization from alcohol gave colourless needles, m.p. 325–326°c. The yield of pure perlolidine base was 125 mg.

Perlolidine Base.—A small amount of base was isolated from rye-grass extracts by Grimmett and Waters(1) during the large-scale preparation of perloline. This material was obtained from the hydrochloride by chloroform extraction from carbonate solution, forming needles m.p. 323°c. Distillation of the base at 0·01 mm. gave colourless neddles m.p. 323°c., apparently identical with the material obtained by oxidation and showing no depression of melting-point on admixture. There was also identity of microchemical slide reactions of all preparations. Analyses of several preparations gave—

—	Found.	Theoretical for $C_{25}H_{18}O_{3}N_{4}$.
C	73·1, 73·5, 73·3, 74·3 ..	73·89
H	4·5, 4·5, 4·3, 4·2	4·43
N	14·9, 14·0, 13·9, 14·0, 14·3 ..	13·79

Kjeldahl N was low, 7·5, and the base was partly unaltered; methoxy and CH_3(N) determinations were negative.

Perlolidine base forms colourless needles m.p. 323–326°c., insoluble in water, slightly soluble in hot alcohol (less than 0·5 per cent.), acetone, chloroform, ether, ethyl acetate, and other solvents. Solutions have a dull-blue fluorescence. From hot alcoholic solution it separates in small needle clusters. It is soluble in phenol, giving a molecular weight of 203. On diluting the phenol solution with water and adding a drop of acid the fluorescence did not appear until a considerable dilution had been reached. The base can be precipitated from solutions of its salts by ammonia diffusion, separating in needles.

Perlolidine Hydrochloride.—The base was dissolved in a little hydrochloric acid and taken down to dryness under vacuum. The hydrochloride was recrystallized from hot alcohol in faintly-yellow needles which did not melt at 350°c., but darkened and sublimed slightly from 300°c. The hydrochloride from perlolidine isolated by Grimmett and Waters(1) did not melt at 350°c. Analysis gave—

—	Found.	Theoretical for $C_{25}H_{18}O_2N_4$, 2 HCl, 2 H_2O.
C ..	58·2 . ..	58·25
H ..	4·5	4·66
N ..	10·9, 10·9 . ..	10·87

Halogen could not be determined directly, as silver nitrate gave a precipitate with perlolidine.

It is readily soluble in water, appreciably in alcohol. Aqueous solutions have a strong blue-violet fluorescence visible at 1 part in 6,500,000 in sunlight. This fluorescence is indistinguishable from that of harmine or harmol hydrochlorides, which, however, are visible only to about 1 in 500,000, and ergometrine hydrochloride visible to 1 in 100,000.

Microchemical Slide Reactions of Perlolidine.—Neutral or slightly acid solutions of the hydrochloride gave precipitates not of great insolubility, and crystallizing fairly easily, with many alkaloid reagents. Potassium bismuth iodide gave a red, highly insoluble precipitate crystallizing slowly and incompletely to small needle clusters. Potassium mercuric iodide gave in moderately concentrated solutions a precipitate crystallizing readily in isolated rods with curved ends, or large clusters of thick needles with curved ends. This is the most specific reaction for identifying perlolidine. Gold chloride in concentrated solutions formed large spheroidal clusters, and gold bromide spheroids and fine needle clusters. Picric acid and potassium tri-iodide gave amorphous precipitates forming slowly fine needles in clusters. Mercuric chloride gave readily large curved clusters of fine needles. Potassium chromate in concentrated slightly acid solution gave large yellow clusters of fine or thick needles, very characteristic in appearance. Sodium carbonate or bicarbonate gave the base as an amorphous precipitate soon forming incompletely fine needle clusters or huge masses of hair-like material, with characteristic swellings along the hairs. Sodium hydroxide formed a precipitate similar in appearance, the solid particles appearing blue fluorescent. Silver nitrate gave a heavy gelatinous precipitate. Potassium mercuric bromide and potassium cadmium bromide, potassium bromide, and cyanide formed no precipitates. Harmine and harmol give sparingly soluble precipitates with potassium cyanide.

Structural Evidence on Perlolidine.—Perlolidine is soluble in sodium hydroxide to a colourless solution with slight green fluorescence, and is precipitated from this solution in needles by carbon dioxide. The aqueous

solution of the hydrochloride gave no colour reaction with ferric chloride, and the Millon reaction was negative. Copper sulphate or acetate formed no precipitate with aqueous solutions. Aqueous solutions readily reduced permanganate and dichromate. No reduction occurred with sulphur dioxide, nitrous acid, or stannous chloride. No indole or carboline reactions were shown with *p*-dimethylaminobenzaldehyde, vanillin, or pine shavings, and the Adamkiewicz reaction, also with addition of ferric chloride, was negative. There was no apparent action after long refluxing with acetic anhydride, or shaking with methyl sulphate and alkali. Hot concentrated nitric acid or lead tetraacetate in acetic acid had no ready action.

Intensely Coloured and Fluorescent Bodies from Perloline

The " Nitro " Product and its Conversion to a Coloured Fluorescent Body.—Perloline hydrochloride was dissolved in a 25 per cent. solution of acid containing equal amounts of hydrochloric and nitric acid, and the solution was boiled. A brown precipitate formed, which dissolved on further boiling. The solution was cooled and the base precipitated by ammonia diffusion. It was dissolved in dilute hydrochloric acid and repeatedly ammonia diffused, forming a red material m.p. 185–190°C, with sintering and darkening from 150°C. Analysis gave: C = 56·24; H = 4·06; N = 7·36, 7·48, 7·0, 7·48; $(OCH_3)_4$ = 14·2, 13·8, 14·0; $CH_3(N)$ and $CH_3(C)$ = Nil. It was soluble in camphor, but decomposed rapidly at the high temperature. The base was insoluble in water and ether, very slightly soluble in caustic alkali and carbonate, readily in acids. It was extracted by chloroform from acid and alkaline solution. In the presence of alkali the chloroform solution was orange-yellow with a strong green fluorescence; in the presence of acid it was yellow without fluorescence. This material, dissolved in dilute acid and exposed to bright sunlight for one hour or so, went green with an intense red fluorescence of the colour of cuprous oxide.

500 mg. of perloline hydrochloride were kept slowly boiling in a 50 per cent. solution of equal amounts of hydrochloric and nitric acids for fifteen minutes, when the solution was wine-red. After cooling, it was almost neutralized with sodium hydroxide, taken down to a small volume, acetone added, and the inorganic salts removed. The resulting solution was made alkaline and shaken exhaustively with chloroform. The aqueous non-extractable fraction was taken up in acetone and exposed to bright sunlight. Before exposure it was red; after exposure, a chlorophyll green. The chloroform extract was shaken with 50 per cent. hydrochloric acid, and this aqueous fraction was taken up in acetone and the salts removed. Before the exposure the solution was yellow; afterwards a chlorophyll green.

100 mg. of perloline in 1 ml. of concentrated nitric acid and 10 ml. of hydrochloric acid was treated as above, the aqueous fractions giving on exposure a green colour with strong red fluorescence. 100 mg. of perloline hydrochloride was treated with 10 ml. of concentrated hydrochloric acid and 2 g. of sodium nitrite and sent through the same stages as above. The chloroform insoluble fraction was taken up in acetone and salts removed. Before exposure it was yellow; afterwards, chlorophyll green.

The Perchlorate Precursor and its Coloured Fluorescent Material.—100 mg. of perloline hydrochloride were dissolved in 10 ml. of water, 5 ml. of 60 per cent. perchloric acid added, and the solution boiled. The perchlorate dissolved on boiling for some time. On further concentration, white fumes appeared and a violent action took place. The solution was boiled for a further three minutes, cooled, made slightly alkaline with potassium carbonate, and the precipitated potassium perchlorate filtered off. The solution was made slightly acid with perchloric acid, taken to dryness,

and extracted with acetone. This procedure was repeated to remove salts. The solution contained perlolidine and the precursor for the formation of the coloured fluorescent body. It was made alkaline with potassium bicarbonate and shaken with chloroform, when most of the perlolidine was removed, and the precursor left in the aqueous solution. This was evaporated and extracted again with acetone to remove salts. It was extracted by chloroform and the residue taken up in water and evaporated. Properties of the precursor have not been studied. It is insoluble in chloroform, gives no precipitate with ammonia, and is soluble in alkali.

The precursor exposed to bright sunlight in slightly acid solution within two minutes goes green with a strong red fluorescence. If the exposure is continued the solution becomes saturated with the coloured body formed, and a green-black precipitate separates on standing. This precipitate was washed with 10 per cent. hydrochloric acid in which it was almost insoluble. It was readily purified by dissolving in concentrated formic acid and precipitation by addition of water. It could also be recrystallized from concentrated sulphuric acid by dilution with water. Analysis gave: C = 58·17, H = 3·73, N = 5·34. This material is insoluble in acetone, alcohol, ether (unlike porphyrins), chloroform, aniline, slightly soluble in acetic acid and pyridine. It is very slightly soluble in potassium carbonate and hydroxide with a pink colour, soluble in hydrochloric acid (1 : 2), 50 per cent. sulphuric acid, and in concentrated phosphoric and formic acids. In hydrochloric and formic acids it is intense blue with strong red fluorescence. In concentrated sulphuric acid the fluorescence is eosin-like, but on some dilution becomes the same as in hydrochloric acid. It can be colloidally suspended in potassium carbonate. The photo reaction takes place when ultra-violet light is cut out, but not with ultra-violet present and visible cut out. The acid aqueous solution absorbs in three bands, the two strongest being about 630–650 mμ and at 680–720 mμ. The absorption spectrum is less defined and simpler than those of porphyrin derivatives. The compound is not reduced by stannous chloride in acid solution ; permanganate or ferricyanide oxidizes it to a colourless material.

By the action of ammonium persulphate in the cold on the above material there results a material soluble in chloroform with a violet colour. This new material is also soluble in acetone, insoluble in sodium hydroxide. Once precipitated with hydroxide it is no longer chloroform and acetone soluble, but dissolves readily in 50 per cent. hydrochloric acid to a material resembling the coloured body for which it was made. Some rhodines display similar characteristics.

ACKNOWLEDGMENTS

We wish to acknowledge our thanks to Dr. R. Lemberg, Institute of Medical Research, Sydney, whose advice in two private communications concerning the coloured bodies proved very helpful. Thanks are due to Mr. C. L. Carter, University of Otago, for micro carbon-hydrogen determinations on perlolidine base and hydrochloride. Carbon-hydrogen and some nitrogen determinations on perlolidine base and the coloured bodies were due to Mr. R. N. Seelye, Department of Agriculture, Wellington, and to Professor McBeth, University of Adelaide.

REFERENCES

(1) GRIMMETT, R. E. R., and WATERS, D. F. (1943): *N.Z. J. Sci. & Tech.*, **24**, 151B.
(2) WHITE, E. P., and REIFER, I. (1945): *Ibid.*, *27*, *(Sec. B)*, 38.
(3) COULTHARD, C. E.; LEVENE, H. H. L.; and PYMAN, F. L. (1933): *Biochem. J.*, *27*, 727.
(4) FISCHER, O., and TAUBER, E. (1885): *Ber. 18*, 402.

ERECHTHIAS FULGURITELLA WALK. (LEPIDOPTERA) INHABITING PINE CONES

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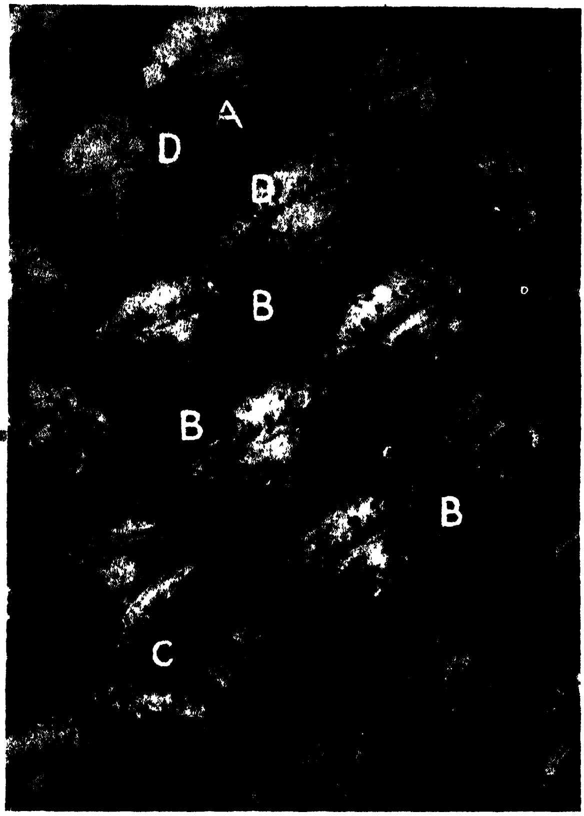
Summary

Associated with cones of *Pinus radiata*, a native moth, *Erechthias fulguritella*, is recorded from the Nelson Province. Its larvæ invariably destroy the seed in infested cones, but have a negligible effect at present on seed production.

UNTIL now nothing has been recorded about the host association of a native species of moth, *Erechthias fulguritella*, which was described in 1863 by Walker(1). Accompanying a description of this species, Hudson(2) contributes the following information : " This rather obscurely marked species has occurred at Wellington, Christchurch, Dunedin, Lake Wakatipu, and Invercargill, but is rarely met with. The perfect insect appears from November till February and frequents forest or scrub." In his " Supplement," Hudson(3) remarks : " Also from Wyndham and Te Anau - Manapouri district, where common."

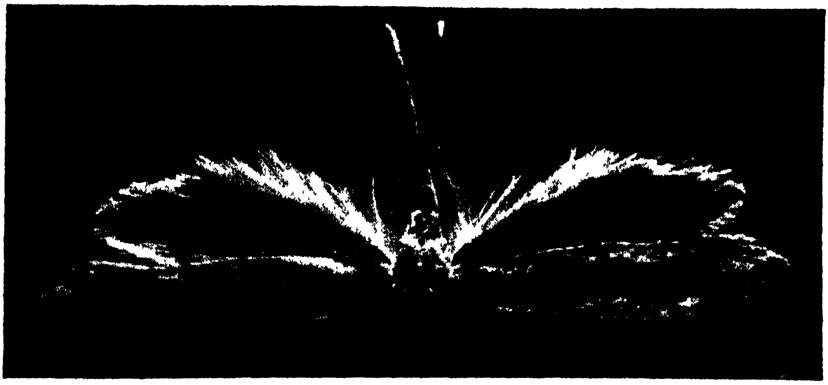
The writer is able to add Nelson to these localities by the collection of a single specimen in October, 1926. In late August and early September of 1942 the author was investigating the position of the Ichneumon parasite, *Rhyssa persuasoria*, in relation to its host, the horntail borer, *Sirex noctilio*, in a pine plantation consisting mainly of *Pinus radiata* at Waiwhero, about four miles south of Motueka, in the Nelson Province. Certain pine cones on trees felled and remaining intact on the forest floor from the previous season showed a remarkable lightness in weight when compared with others and were of a distinctive colour. These facts, associated with external evidence of frass from larvæ feeding within, led to the collection of a number of cones. These cones were kept in glass containers, and in November adults of *E. fulguritella* appeared from some of them, accompanied by a Bethylid, *Parasierola*, which is probably parasitic on the larvæ. *E. fulguritella* larvæ feed inside the cone, generally on the bract and ovuliferous scales in the vicinity of their points of contact, and invariably destroy the seeds. Adults emerge at any point on the outer exposed surface of the bract scales, and the moth pupæ project for three-quarters of their length (Fig. 1). There is possibly an association between the light-weight cones and their infestation by the fungus *Diplodia pinea* (Desm.) Kickx, as practically every light-weight cone showed externally pycnidia of *D. pinea* (Fig. 1). Birch(4) believes that the fungus occurs as a saprophyte of the seed coats and in the interior of dead seed. Those lightweight cones not occupied by *E. fulguritella* contained mainly living, but also a few dead, seeds. The effect of *E. fulguritella* as a controlling agent in *Pinus* seed production is negligible owing to the small number of cones attacked.

The description given by Hudson(2) of the adult of *E. fulguritella* is: " The expansion of the wings from ½ in. to ⅝ in. The fore wings are pale brownish-ochreous with the costal area more or less clouded with darker brown ; there are several cloudy blackish streaks in the disk, extending from the base to the apex, the lowest of these emitting three blunt projections



[*Photo by Miss V. Robinson, Cawthron Institute.*

FIG. 1.—Pine cone showing—A, larval frass; B, emergence holes; C, empty pupæ of *E. fulguritella*; and D, pycnidia of *Diplodia pinea.*



[*Photo by Miss V. Robinson, Cawthron Institute.*

FIG. 2.—Adult of *E. fulguritella*, tricolour variety.

towards the dorsum; the dorsal area is very pale brownish-ochreous, often almost white; there is a black spot at the apex. The hind wings are very pale greyish-brown, darker towards the apex." In certain particulars this description does not adequately cover the many variations of colour disposition and their intensities. Many specimens have the middle—base to apex—of the fore wings of a uniform unstreaked darker-brown colour with the costal area clouded in a much lighter shade of brown, giving a very marked three-colour zoning to the wings. In others the lowest part of the middle darker marking, instead of having three blunt projections towards the dorsum, has three more acute markings directed sharply towards the base of the wing with the very narrow intersecting areas white in colour. Other variations also exist. The adult insect is shown in Fig. 2.

REFERENCES

(1) WALKER, F. (1863): List of Specimens of Lepidopterous Insects in the Collection of the British Museum, Part 28, 548.
(2) HUDSON, G. V. (1928): "Butterflies and Moths of New Zealand," 366.
(3) ——— (1929): *Ibid.*, Supplement, 463.
(4) BIRCH, T. T. C. (1936): *Diplodia pinea* in New Zealand. *N.Z. State Forest Service Bull.* 8, 8.

NOTE ON *BIRONELLA (BRUGELLA) HOLLANDI* TAYLOR

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Summary

The Anopheline genus *Bironella* has its centre of distribution in New Guinea. *Bironella (Brugella) hollandi* Taylor was described from Kavieng, New Ireland, and has the most easterly distribution of any member of the genus. The following note records its known distribution in the Solomon Islands, and gives some information on its biology and a description of the egg.

IDENTITY

SPECIMENS from the Solomons were found to fit the description of *B. hollandi* fairly closely. Mr. D. J. Lee kindly supplied drawings of the male genitalia of the type which confirmed the identification as *hollandi*. A male reared from the egg at Vella Lavella was found to be identical in male genitalia with males from Banika and Guadalcanal.

DISTRIBUTION

This species was first taken in the Solomons by Major W. G. Downs, United States Army Medical Corps, on Banika Island, in the Russell Group. The writer also secured specimens from Banika and later found the species to be common in jungle streams on Guadalcanal. It was later taken in Vella Lavella, and specimens from Mono Island in the Treasury Group were seen. Major Downs later reported it from New Georgia and Bougainville. No sign of it was seen on Nissan or Green Island, where there was no suitable water.

It is thus recorded from a chain of islands from New Ireland to Guadalcanal, and it is quite likely that it will be found on some of the larger islands of the lower Solomons, such as Malaita and San Cristobal. The writer saw no sign of it on Efate Island, New Hebrides, nor was it reported by American entomologists from Espiritu Santo, farther north. The limit of its distribution therefore does not reach as far south as that of *B. gracilis*, which reaches Cairns, in Queensland.

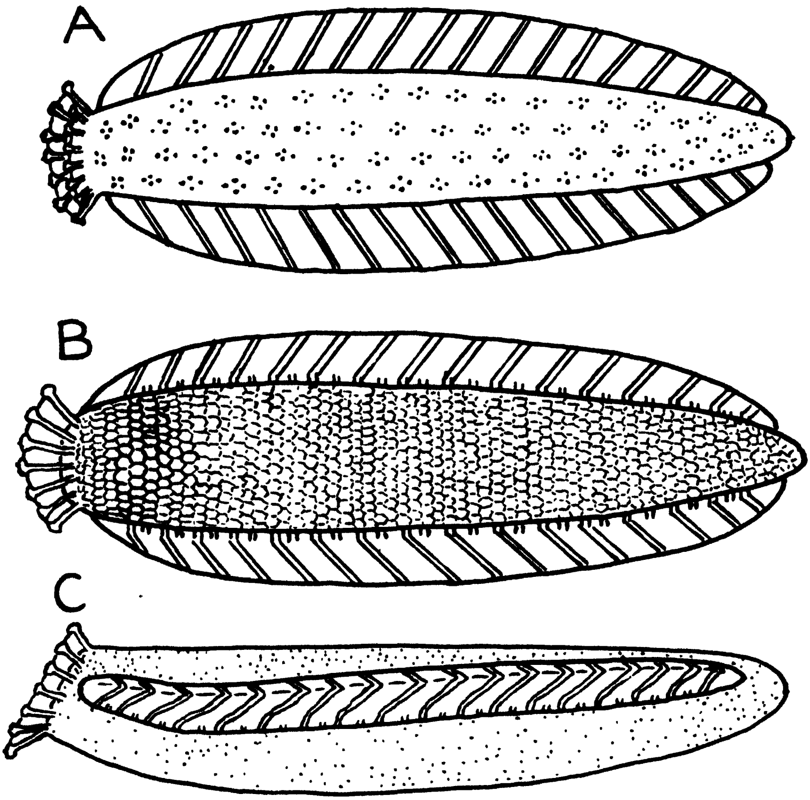

FIG. 1.—*Bironella (Brugella) hollandi* Taylor. Egg: A, dorsal; B, ventral; C, lateral.

BREEDING-PLACES

This is characteristically a jungle species, found in dark jungle streams on Guadalcanal, Banika, and Vella Lavella, &c. In these locations it was usually much more abundant than *Anopheles punctulatus* var. *moluccensis*. It was taken in swampy streams containing taro, in an open coconut plantation not far from the jungle edge, and also in still seepage pools or springs in a Native garden in the jungle. In several cases it was abundant where the streams had been dammed up at the jungle edge, particularly amongst floating debris of leaves, twigs, &c. It was taken in sluggish streams, but also in the quieter eddies of a fairly swift jungle stream on Guadalcanal. It occurred in jungle-covered streams on the flats and also in deep ravines in hilly country.

LIFE-CYCLE

Laboratory rearings on Vella Lavella of eggs collected in the field from a swampy patch in a native garden at Joroveto gave the following results :—

	Days.
Incubation period (estimated)	3
Larval period (estimated)	19
Incubation and larval period observed (eight specimens) ..	22
Pupal period observed (five specimens)	1·8
Total period, oviposition–emergence (five specimens).. ..	23·8
Minimum period, oviposition emergence	22
Maximum period, oviposition emergence	26

These larvæ were kept in a beaker in the laboratory and fed on chopped flies and powdered biscuit.

Two *Anopheles punctulatus* var. *moluccensis* eggs collected at the same time and reared in the same way produced adults in fifteen and eighteen days respectively. Under the same conditions it appears that the life-cycle of *B. hollandi* is significantly longer than that of *moluccensis*.

HABITS

This species was never taken biting man, nor was it caught in night-catches or light traps, and was never found in tents. The only adults seen were those which were reared. Laboratory-reared specimens showed no inclination to bite man, though every endeavour was made to make them do so. They fed readily on glucose solution.

RELATION TO HUMAN MALARIA

Owing to its habit of not frequenting dwellings, it is presumed to be unimportant as a vector of human malaria. The presence of this species on Guadalcanal led to the beginnings of species sanitation, in that the dark jungle streams entering the foothills supported predominantly *B. hollandi* and could be largely disregarded as a source of malaria vectors.

MORPHOLOGICAL

Lee and Woodhill, in their revision of the Australian *Anophelini*, have described the species. The larva, in life, is usually a deep black, much blacker then *moluccensis*. The fourth abdominal segment is white or unpigmented and in strong contrast to the body colour. The larvæ of *moluccensis* when they show a white band, and it is frequently difficult to discern, have it on the third abdominal segment. This difference, which was first noted by Major Downs, was useful in rapid identification of larvæ in the field, since the white band in *B. hollandi* appears to be behind mid-length, while in *moluccensis* it is at or before mid-length.

THE EGG

This has been figured by Lee and Woodhill, but their figure, probably due to inadequate material, fails to show the striking characters of the floats, in particular. The following description is made from eggs collected at Joroveto, Vella Lavella, and preserved on filter paper moistened with formalin :—

	Mm.
Length, including rosette (mean of eight eggs)	0·52
Length, without rosette	0·48
Greatest width of egg proper	0·11
Width of float	0·04
Depth of egg	0·09

The *floats* extend nearly the full length of the egg. In transverse section they are V shaped with the dorsal arm of the V nearly horizontal and its point of attachment to the egg nearer to the mid-dorsal line than that of the ventral arm, which is at the angle of 50–60° to the horizontal and is inflexed just before the point of attachment. The ribs are about sixteen in number, and on the dorsal surface of the float form a parallel series of straight ribs running in a postero-lateral direction from the inner margin of the float. This is in contrast to the eggs of many other anophelines, in which the floats are rounded and not angled and the ribs are radially arranged on either side of the mid-length of the float. On the ventral surface the ribs are continuous with those of the dorsal surface and form a parallel series with an inflexion before the point of attachment. Between the origins of the ribs at the ventral point of attachment are short ribs which do not extend beyond the outer margin of the inflexed portion of the ventral surface of the float. In lateral view the ribs are V shaped with the base of the V anterior.

SCULPTURE

Dorsally the surface of the egg proper shows a pattern of relatively large papillæ grouped in fours and fives. Ventrally the surface of the egg is hexagonally reticulate. On the anterior or micropylar end of the egg enclosed by the rosette are about six papillæ. A conspicuous crown or rosette forms a cup-like structure enclosing the micropylar area. It consists of about twelve ribs, the distal ends of which are capitate (and crenulated ?). Between the ribs is a membrane which encloses the cup. Ventrally the ribs are longer and their bases nearer to the anterior end of the egg.

REFERENCE

LEE, D. J., and WOODHILL, A. R. (1944): The Anopheline Mosquitoes of the Australian Region. *Sydney Univ., Dept. Zoology, Monograph No. 2.*

A PORTABLE COUNTING RATE METER FOR G-M TUBES

By J. F. McCAHON, Radio Development Laboratory, Department of Scientific and Industrial Research

[*Received for publication, 2nd October, 1945*]

Summary

A description is given of a portable counting rate meter and high-tension supply for Geiger-Muller tubes, suitable for use in prospecting for radioactive minerals.

WHEN work on the release of atomic energy from uranium was nearing success, a search was started in many countries, including New Zealand, for possible sources of uranium-ore. As suitable apparatus for this work was not readily available, it had to be built locally.

Work on portable G-M counter gear was started in September, 1944. This paper describes the latest model, developed and built at the Radio Development Laboratory, Wellington.

It has been designed for use under field conditions, has been made as small and light as possible, and is rainproof. The chassis and outer case are made of duralumin (Fig. 1). There is a channel round the front panel holding a gasket of ⅛ in. square rubber strip, against which the outer case is pressed by two screw slips. All parts on the panel are sealed with varnished gaskets, the meter being mounted behind a perspex window. The shafts of the rotary switch and potentiometers are kept well greased and the toggle switch is covered by a rubber cap. No water had entered the instrument after several hours' use in heavy rain.

The overall dimensions are 4½ in. by 6½ in. by 7¾ in. deep, and the weight, complete with batteries, but without the G-M tube, is 7 lb. The G-M tube is attached by means of a plug and cable, and weighs 1¾ lb. It is described elsewhere in this issue by A. G. McLellan.

The high-tension supply for the G-M tube seen on the near side in Fig. 2 employs a 1S4 with inductive load, and a 1S5 in a multivibrator circuit (Fig. 3). The sharp cut off of current through the choke produces high-voltage pulses which are rectified on the 1S5 diode. A similar circuit used overseas employs a 3A8, with a choke in the pentode plate circuit, and coupling for the triode grid taken from the screen. With the 1S4 this was unstable, and the present circuit was found to be much more reliable. The output voltage is varied by means of the potentiometer in the screen circuit of the 1S4. This is not accessible from the front panel, but is adjusted to give the correct voltage for the tube used (generally 1,050v) with the B supply set correctly. After this, all that is necessary in operating the counter is to see that the B voltage is correct. This is provided for in one switch position in which the meter reads the B voltage. A 5K potentiometer is used to adjust this to 35v, which allows changes in battery voltage to be compensated for.

At 35 volts supply the maximum output is 1,400v, and at 45v it is 1,700. At 1,050v output the B battery drain is 5 ma.

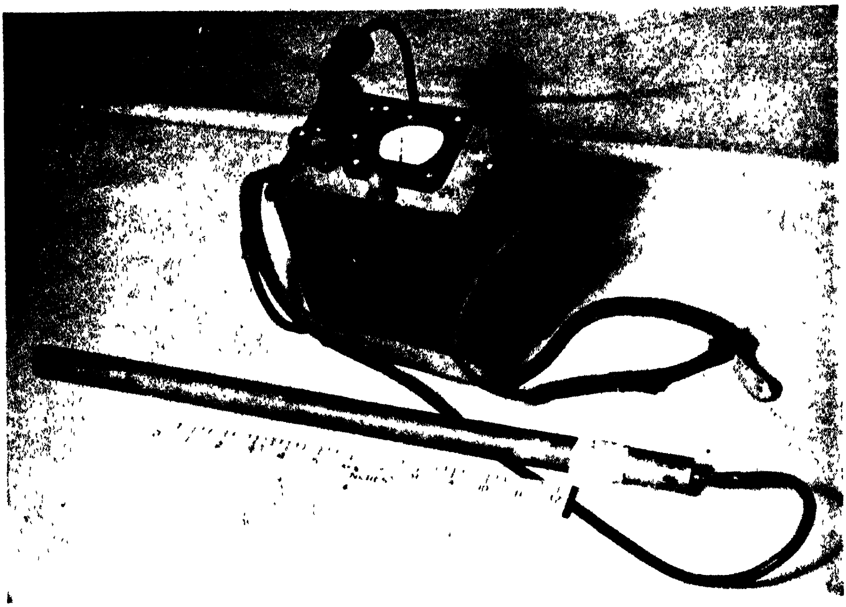

Fig. 1.—Complete instrument and Geiger-Muller tube.

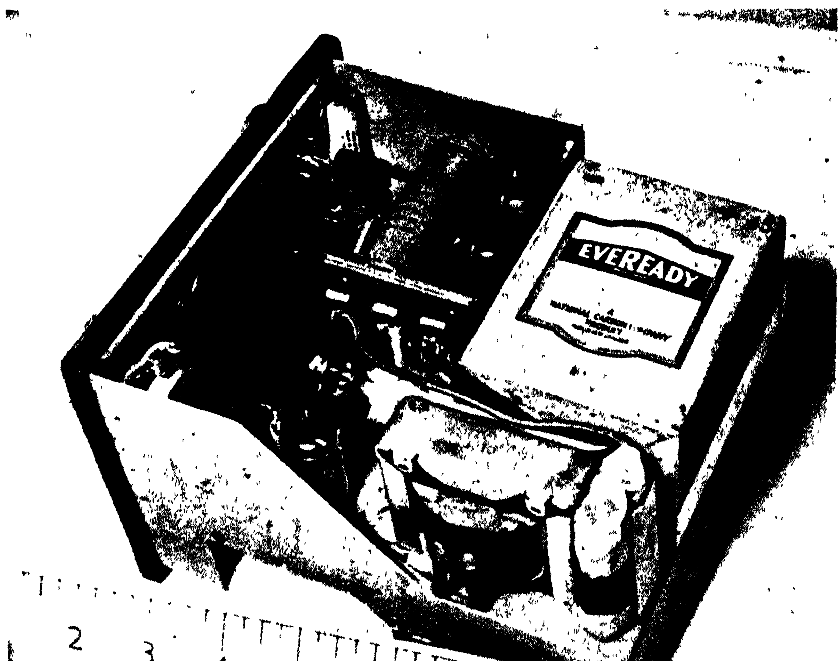

Fig. 2.—Top view of chassis.

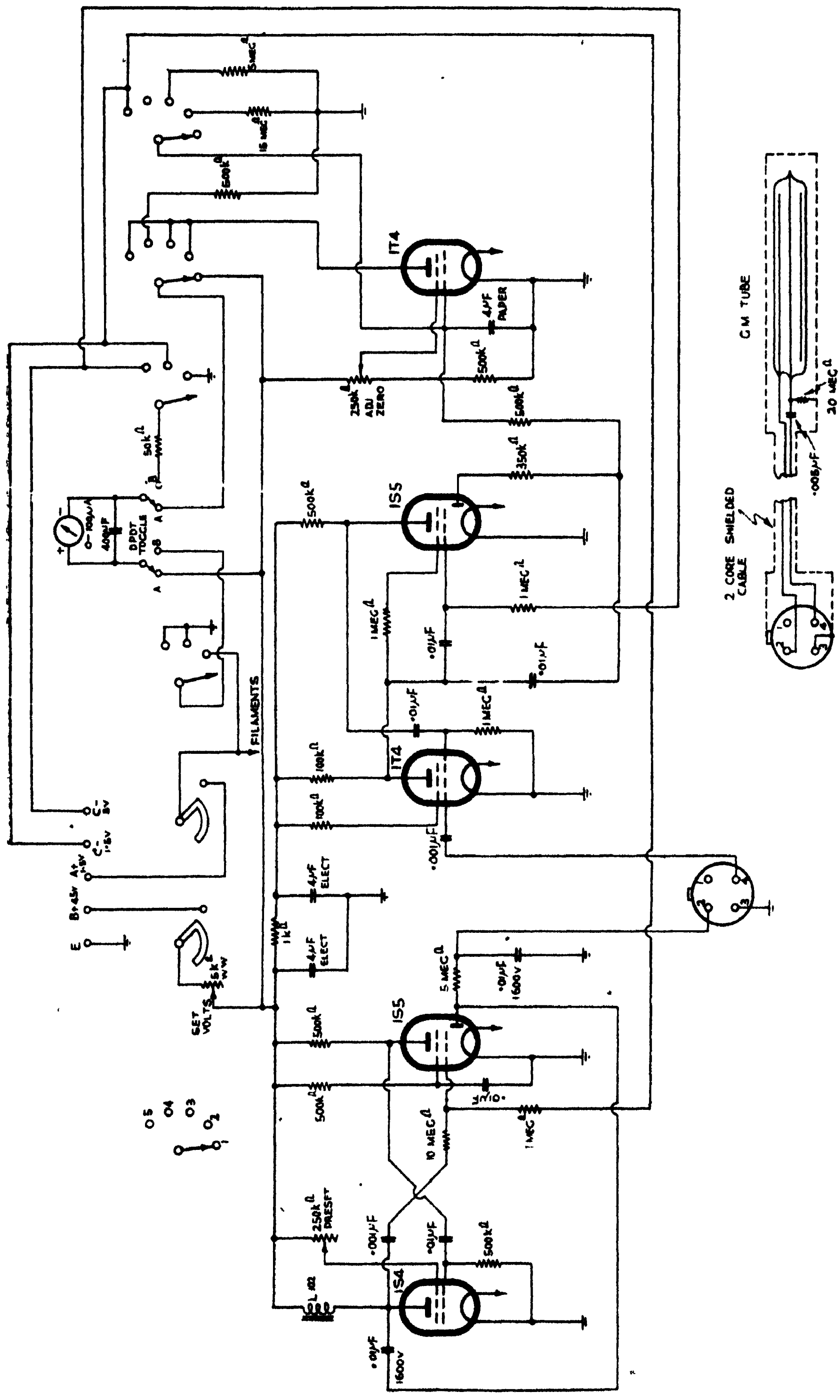

Fig. 3.—Circuit diagram.

The counting rate meter itself is rather sensitive to B voltage variations, and so is also on the adjusted supply, being connected through a decoupling circuit. Both the counting rate meter and high-tension supply are practically unaffected by reasonable changes in A battery voltage.

The counting rate meter on the far side in Fig. 2 consists of a flip-flop circuit using a 1T4 and 1S5, which converts the pulses from the G-M tube to a standard size. These are then rectified on the 1S5 diode, and made to charge a 4μF. condenser, which has a high resistance leak across it. The resistance in series with the diode, and the leak resistance, can both be used to vary the sensitivity, which is not affected by the size of the condenser. However, as the pulses are spaced at random intervals, a long time constant is needed to give a steady meter reading, and, for accuracy, a large condenser must be used. (This is seen beside the A battery in the under-chassis view—Fig. 4).

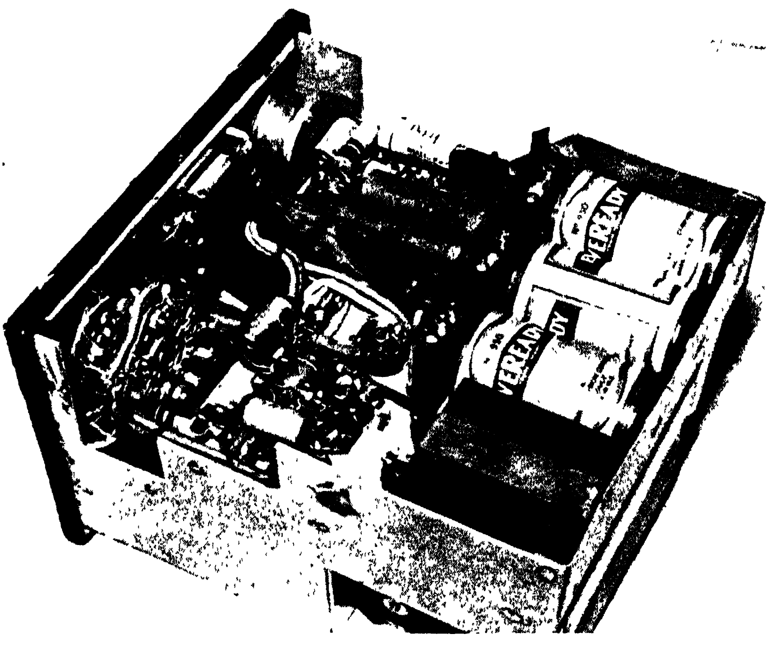

FIG. 4.—Under chassis view.

The voltage developed across the condenser is applied to the grid of a 1T4, whose plate current is measured, being lower the higher the counting rate. The meter is adjusted to full-scale reading by means of the screen potentiometer, with $-1\frac{1}{2}$v on the grid. Rates of less than 80 counts per minute are then off the scale, the whole of which is then available for the useful part of the range. The background of the G-M tubes is about 80 counts per minute. With this arrangement the meter may be overloaded under certain conditions. The 400μF. condenser across it gives sufficient damping to prevent damage due to its slamming over hard.

Two ranges are provided by the use of different values of leak across the condenser. The high range with 5 meg. leak covers 200 to 1,500 counts per minute and the low range using 15 meg. covers 80 to 300. The scale is

approximately logarithmic. A calibration graph is used, the calibration being done by means of a multivibrator supplying pulses at an adjustable rate, to a mechanical counter and to the counting rate meter. A buffer stage having a very high output impedance is used to feed the counting rate meter in order to avoid affecting the pulse length of the flip-flop.

The switching arrangements allow the meter to be used for measuring battery voltages, thus avoiding the need for a separate test meter in the field.

Toggle Switch Position.	Rotary Switch Position.	Meter reads.
B	1	No connection.
	2	Filament volts on load.
	3	Bias volts — 1·5v.
	4	Bias volts — 3v.
	5	No connection.
A	1	Off—meter shorted for additional damping when being carried.
	2	Low range.
	3	High range.
	4	B voltage.
	5	$-1\frac{1}{2}$v on grid of output tube—set meter to full scale.

In operation, the switches are first turned to the A-4 position and the B voltage set to read 70 on the scale, then to A-5 when the meter is set to full-scale reading, and then to A-3 or A-2 when the needle will slowly drop until it reaches a steady reading in two to three minutes. The preliminary adjustment is only necessary occasionally.

The drain from the A battery is 300 ma., giving a battery life of at least six days of normal field use. The B drain is 5 ma. and the B battery has not yet needed changing after seven days' use. It is anticipated that it will last much longer than that. The bias battery consists of two penlite cells and is mounted by means of a clip at one end of the H.T. choke.

Other types of counting rate meters are described by Leon F. Curtiss in the *U.S. Bureau of Standards Journal of Research, Volume 23,* Papers R.P. 1223 and 1246, and *Volume 25,* R.P. 1330.

ACKNOWLEDGMENT

I wish to acknowledge valuable help and suggestions in this work from Mr. G. H. Fraser, of this Laboratory.

AN ALPHA-RAY IONIZATION CHAMBER FOR RADIOACTIVITY MEASUREMENTS

By I. C. McKELLAR, Radio Development Laboratory, Department of Scientific and Industrial Research

[*Received for publication, 8th October, 1945*]

Summary

A semi-portable ionization chamber is described suitable for rapid measurements of total alpha-ray emission from the surface of sand or powdered rock samples.

RECENT interest centred on the uranium content of New Zealand rocks, beach sands, and dredge concentrates required the testing in the laboratory of several hundred samples collected during the past year.

The present apparatus is similar to an ionization chamber which has been in continuous use for four months, and includes some improvements in design. Construction was carried on parallel with that of a counting rate meter described by J. F. McCahon in this issue, and provides a check on field tests made with this instrument.

DESCRIPTION

The apparatus is similar to that used by C. N. Watson-Munro(1), in that a Lindemann electrometer is used with its fibre suspension connected to a central electrode running along the centre of an aluminium chamber, and supported at one end only by a polystyrene bush surrounded by a brass guard ring.

A negative potential of 60 volts is applied to the outside of the ionization chamber, and two approximately equal voltages, opposite in sign, are applied through high resistances to the two pairs of electrometer plates.

The electrometer in this condition acts as a sensitive measurer of small changes of voltage on the central electrode.

The tip of the electrometer needle is viewed in a low-powered microscope (magnification $\times 63$) fitted with a scale in the eye-piece made up of fifty divisions. Voltage sensitivity of the electrometer can be varied by adjusting the two carbon potentiometers included in the potential divider placed across the 90-volt battery as shown in Fig. 1. An electrometer sensitivity of 25 millivolts per scale division was found very suitable for most work.

The switch S_1 consists of a plunger which is pressed in contact with the central electrode of the ionization chamber by a light phosphor-bronze spring. The switch assembly is completely enclosed and electrostatically shielded by an extension of the earthed guard ring which makes contact with the case of the electrometer.

The plunger is attached to a piece of soft iron, and the switch can be opened by attracting the plunger away from the central electrode by a small permanent magnet. With S_1 closed and S_2, a spring-loaded toggle

switch, open, the central electrode is at earth potential. With S_1 and S_2 closed, a small calibrating voltage can be applied through a potentiometer to the electrometer needle, and its value read off on a millivoltmeter.

Figure 2 shows the Lindemann electrometer and enclosed switch assembly and magnet. The drying tube seen in this view is filled with indicating silica gel. The microscope mount has been removed.

Figure 3 is a photograph of the complete apparatus. The battery box in the background contains the electrometer plate batteries and the ionization chamber battery. These are enclosed in an inner sheet-metal box which is thermally insulated by over an inch thickness of kapok and mounted centrally inside the wooden box shown.

The two carbon potentiometers are mounted on the inner metal box, and extensions of ebonite brought out from the shafts. Temperature control of batteries and resistors was found to improve the stability of the instrument's electrical zero greatly.

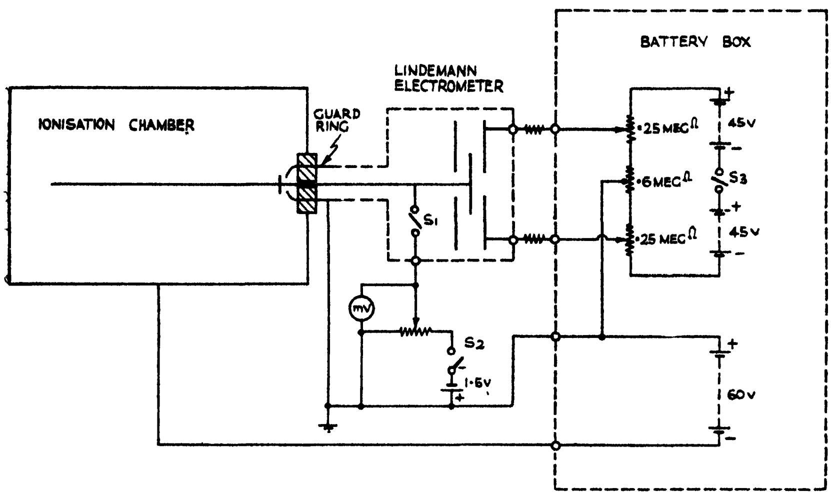

FIG. 1.—Circuit diagram.

S_3, the battery on-off switch, is simply a copper strap joining two terminals on the front of the battery box: shown here disconnected. Toggle switches in the battery leads were found to be a frequent cause of unstable voltages at the electrometer plates.

METHOD OF USE

Samples ground to about —60 mesh are spread on a shallow aluminium tray and placed centrally on the floor of the chamber. Alpha rays ejected from any radioactive material present are responsible for a large percentage of the total ionization of the air in the space between the central electrode and the walls of the chamber.

The negative voltage applied to the ionization chamber is sufficient to sweep all positive ions to the chamber walls before recombination can take place, and with S_1 open this current causes a change of voltage with respect to earth on the central electrode whose rate of change is measured by the rate of movement of the electrometer needle. This is timed with a stop-watch over periods ranging from three to thirty minutes.

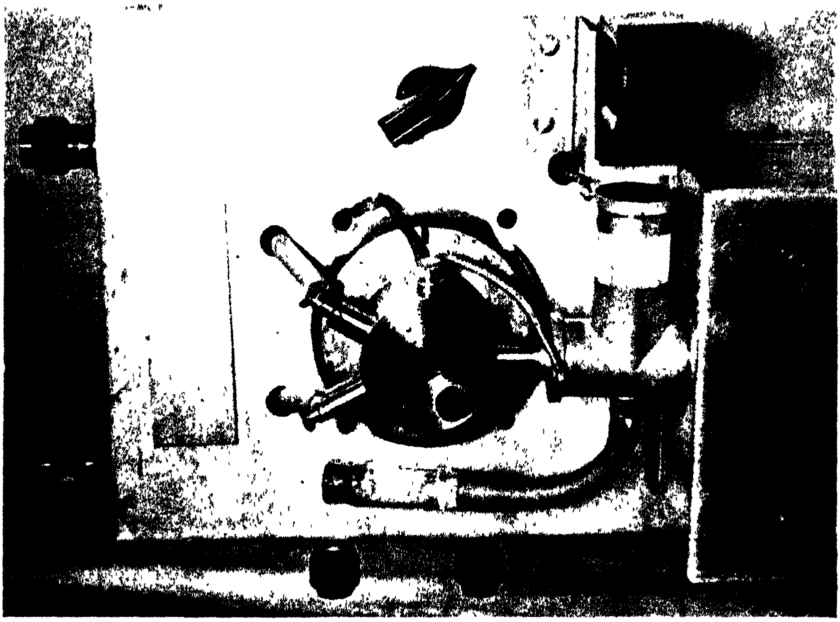

FIG. 2.—Plan view of Lindemann electrometer and connections.

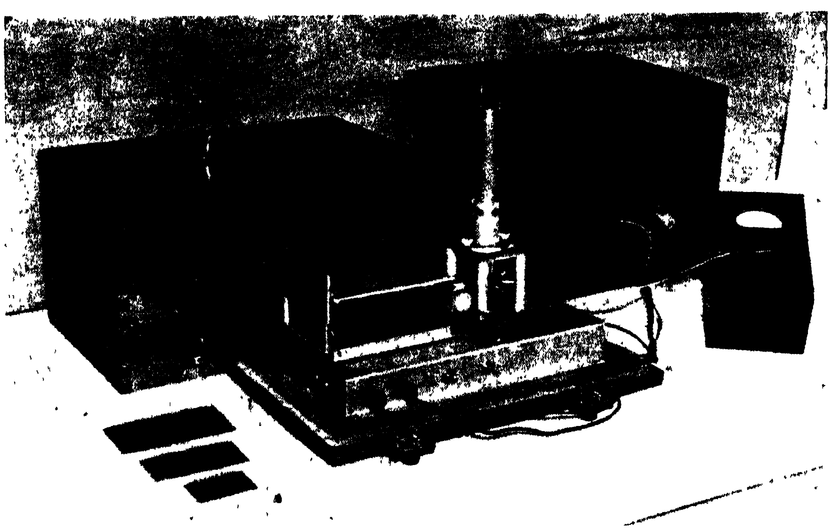

FIG. 3.—General view of apparatus.

Alpha rays emitted from the inside surface of the aluminium chamber, and beta rays ejected by impact of gamma radiation arriving from sources outside the instrument, are responsible for part of the ionization current measured. This "natural leak," the residual ionization produced in the empty chamber, must be measured accurately and kept small and constant if maximum sensitivity is required. The natural leak of this instrument measured on the ground floor of a brick building, a locality known to have a fairly high gamma radiation intensity, is 6 millivolts per minute.

This quantity is subtracted from the total rate of change of voltage observed when a sample is being tested, and the product of the net rate and the combined electrometer and ionization chamber capacity gives a value for the ionization current due to alpha rays emitted from the specimen. The area of the tray is known accurately, and this value is converted to ionization current per square centimetre of surface of specimen.

CAPACITY MEASUREMENTS

The capacity to earth of the central electrode and electrometer needle was found in an earlier instrument by constructing two standard coaxial cylinder condensers, the difference in their capacities being known by calculation from their physical dimensions. These were designed to fit into the shield surrounding the central electrode in place of the switch assembly S_1. A fairly intense source of gamma radiation was placed near the ionization chamber, and the time required for the electrometer needle to move between two fixed points on the microscope eye-piece scale was found with first C_1 and then C_2 in parallel with the unknown capacity C, and the time observed with no added capacity.

If t_1, t_2 and t are the three time intervals respectively, then $\frac{t_1 - t_2}{t} = \frac{C_1 - C_2}{C}$ and C can be found. In this way, $C = 7{\cdot}5$ pF. for the earlier chamber. A comparison of the capacity of the present instrument was made by measurements of several samples in both chambers, and their capacities were found not to differ by more than the experimental error.

Theoretical aspects of the ejection of alpha particles from thick solid sources have been discussed fully by Evans(2), and Marsden and Watson-Munro(3) have published the results of a large number of measurements on New Zealand rocks and soils using a similar instrument to that described.

REFERENCES

(1) WATSON-MUNRO, C. N. (1937): "Some Radioactive Properties of New Zealand Rocks." M.Sc. Thesis.

(2) EVANS (1934): *Phys. Rev.* *45*, pp. 29 and 38.

(3) MARSDEN, E., and WATSON-MUNRO, C. (1944): *N.Z. J. Sci. & Tech.*, *26*, *Sec. B*, 99–114.

CONSTRUCTION OF SELF-QUENCHING G-M TUBES

By A. G. McLELLAN, Radio Development Laboratory, Department of Scientific and Industrial Research

[*Received for publication, 25th September, 1945*]

Summary

A description is given of a Geiger-Muller counter tube, suitable for use in prospecting for radio-active minerals.

IT was required to make G-M tubes capable of detecting γ-rays. As these counter tubes were to be made part of a portable instrument, it was decided to use the self-quenching type of G-M tube, or " fast " tube as it is sometimes called, in preference to the non-self-quenching or " slow " tube. This latter tube, despite its rather derogatory title, has several advantages over the fast tube which makes it ideal for semi-standard work in the laboratory—that is, (*a*) its performance is constant with time ; (*b*) variation of performance with temperature is very small. With regard to these characteristics the " fast " tube is inferior(1–6).

The most important characteristic of a G-M tube is its " plateau "—that is, the region of high-tension voltage applied to the tube over which the number of counts per minute for a given radio-active source is substantially constant. This is obviously a doubly important characteristic in portable equipment—the wider the plateau the better. Now, with slow tubes the plateau depends on the external circuit, and with B batteries of 45 volts it is difficult to obtain a very wide plateau, whereas with fast tubes the plateau width is a function of the G-M tube itself—*i.e.*, condition of cathode surface, filling gas, &c.—and they can be constructed with plateaus of 250 volts quite consistently.

The tubes made were filled with argon and ethyl alcohol or helium and ethyl alcohol. The cathodes were of thin copper sheet which fitted in glass tubing (pyrex) of ⅞ in. outer diameter. The central wire was of 250 micron tungsten wire. The lead from the copper cathode was another piece of 250 micron tungsten wire pressed between the cathode and inner glass surface. For convenience in assembling the G-M tube in a brass sheath, its connections were made at one end. This fact, because of the short path over the external glass surface between the central conductor lead and cathode lead, caused initial trouble. This surface leakage path caused spurious counts (worse at high humidities), seriously affecting the plateau. However, by coating the G-M tube with wax and bedding it in wax over the sheath, this trouble was eliminated. In most G-M tubes the central conductor, at the end where the cathode lead comes out, is bedded in glass and connection made at the other end. The leakage path is then many times greater. In either case, for outdoor work the G-M tube must be enclosed in an absolutely watertight sheath.

Connection on to the tungsten leads was made by brazing tinned copper wire on with Easy-flo brazing materials.

The treatment of the copper cathode is important and will be described in detail. The cathode is cut to size accurately and rolled with a piece of brass tubing of diameter slightly less than the inner diameter of the glass

tube, on a piece of sponge rubber. until the cathode when slipped in the glass tube fits tightly. The cathode is then washed in a grease-remover, cleaned in 6M-HNO_3, and then rinsed several times in 0·1M-HNO_3 to remove any copper compounds formed by the stronger acid. It is rinsed at least ten times in distilled water and dried thoroughly. In order not to contaminate it again, the cathode is handled with clean rubber gloves. The cathode is put on the clean brass tubing described above and is inserted into the glass by slipping off the brass into the glass. This is an easy method and does not crinkle the cathode. The G-M tube is then constructed.

When the tube is sealed on to the filling system it is evacuated and filled with dry nitrogen peroxide prepared by the action of 16M. nitric acid on copper and dried by passing over calcium chloride and phosphorus pentoxide. The tube is then heated with a large gas flame until the glass is hot enough to char a piece of newspaper. The copper cathode assumes a purplish oxidized colour. This film of oxide is an essential component of the self-quenching tube, its purpose being to give very low photoelectric emission and high work function. The tube is then evacuated. The pump used was one guaranteed to only 0·01 mm. and a dry ice trap was used.

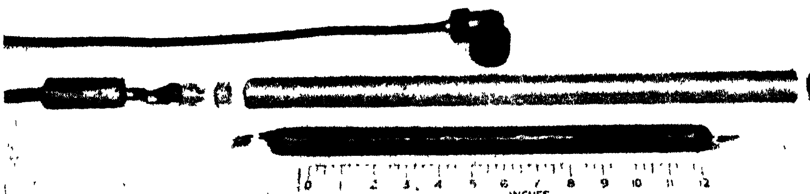

FIG. 1.

A mercury manometer was used for indicating pressures. It was then filled to 0·5 cm. pressure with ethyl alcohol vapour and up to 7 cm. pressure with helium. After sealing off, the tube was placed in a wax bath and then coated with a good layer of wax by successive dippings. It was then assembled in its sheath.

Tubes prepared in this way invariably were good and had similar characteristics. The plateau width was from 200–300 volts.

EFFECT OF TEMPERATURE

Since ethyl alcohol vapour is used it is advisable to use it at pressures such that over the range of temperatures that the G-M counters will be used—*i.e.*, from 0°–20°C.—the alcohol present does not condense. The temperature at which 5 mm. pressure is saturation, vapour pressure for ethyl alcohol is about − 15°C.(7), hence this is a suitable pressure, since only below this low temperature will the alcohol begin to condense.

With this condition satisfied, the gas and vapour filling should behave approximately as a gas filling and certainly in the fact that, above − 15°C., the number of molecules present in gaseous and vapour form will remain constant. Therefore, since the slow counter has very little temperature effect, one would expect the fast counter also to have very little temperature effect above − 10°C. That is, if the observed temperature effect with

fast counters(8) is, as Korff, Spatz and Hillberry say, due to removal of alcohol by condensation. In their experiment, apparently, they used alcohol at nearly saturation pressure at about 0°c.

The effect of decrease of temperature on the tubes made as described here was tested. One tube performed consistently well down to 3°c. (the lowest temperature attainable), whereas another performed badly at 6°c., its plateau there being only 100 volts, as compared with 250 volts at room temperature. Their starting potentials— *i.e.*, beginning of plateau—remained constant for varying temperatures.

Therefore the tubes will not be unworkable at low temperatures, provided an accurate voltmeter is available.

LIFE OF G-M TUBE

The quenching properties of the alcohol depends on its dissociation by absorption of the U.V. photons emitted by the argon or helium ions on neutralization. Thus every pulse registered means the dissociation of a number of alcohol molecules to products that are useless for quenching. According to Korff and Present(9) for every registered pulse 10^{10} alcohol molecules are dissociated. Hence in time such a tube will become useless.

If 2·5 mm. pressure of alcohol are necessary for efficient quenching, we can calculate the number of pulses required to reduce the partial pressure of ethyl alcohol from 5 mm. to 2·5 mm. This number is $2{\cdot}5 \times 10^{8}$, and at 150 counts per minute (normal rate) it would require three years' continuous operation to render the tube entirely useless.

ACKNOWLEDGMENT

All the constructional work of these G-M tubes was due to Mr. W. Barr, of the Dominion Laboratory, who was responsible for many helpful suggestions.

REFERENCES

(1) COPP and GREENBURG (1943): *R.S.I.*, *14*, 205.
(2) HAINES, C. L. (1936): *R.S.I.*, 7, 411.
(3) GINGRICH, N. S. (1936): *R.S.I.*, 7, 207.
(4) EVANS and MUGELE (1936): *R.S.I.*, 7, 441.
(5) STEVER, W. G. (1941): *Phys. Rev.*, *59*, 765.
(6) STRONG (1943): "Modern Physical Laboratory Practice," p. 259.
(7) KAYE and LABY (1943): "Physical and Chemical Constants and Some Mathematical Functions," p. 50.
(8) KORFF, SPATZ, and HILLBERRY (1941): *R.S.I.*, *13*, 127.
(9) KORFF and PRESENT (1944): *Phys. Rev.*, *65*, 274.

THE NEW ZEALAND

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THE MANUFACTURE OF GAUGES AND PRECISION TOOLS

PART I

By J. BROOKE, H. ROBINSON, E. D. MCRAE, and J STEWART, Dominion Physical Laboratory, Department of Scientific and Industrial Research

[*Received for publication, 1st November, 1945*]

Summary

During the war it was the responsibility of the Dominion Physical Laboratory to produce a large proportion of the gauges and precision tools necessary for the manufacture of munitions in New Zealand

This article deals in general terms with the organization and equipment necessary for this work, and in more particular terms with some of the difficulties encountered and the means by which they were surmounted.

The article has been divided into two parts, the first dealing with equipment and the production of limit gauges, while the second discusses precision tools, training of staff, and production methods.

INTRODUCTION

THE mass production of munitions in widely separated parts of the Dominion necessitated the general adoption of the principles of interchangeable manufacture, using precision tools and fixtures in conjunction with limit gauging, for the control of dimensions (see Figs. 1 and 2).

Although modern engineering production methods and single-purpose machines have simplified production processes, they have also increased the necessity for precision work in their tooling and gauging.

Tools and gauges, consequently, are usually grouped together as an article of manufacture, partly because their manufacture calls for accuracy of a high order, and partly because the gauge is required to control the dimensions of a product for which the tool is responsible

This may more readily be appreciated by consideration of the accuracy demanded at various stages of the production set-up.

For example, in the case of the two parts of a shell fuse, which must be capable of being screwed one into the other without resorting to selective assembly, the tolerance permitted the factory producing each of these parts is, say, 0·005 in. It can generally be accepted that the tolerance permitted the manufacturer of the tools used in screwing these parts is about 10 per cent. of this—that is, 0·0005 in. The same tolerance would be allotted to the gauge-maker, who, however, must have measuring equipment capable of controlling and checking his work, which by the same process of reasoning

would be made accurate within a tolerance of 0·00005 in. The reference standard by which this equipment would be checked would be accurate within 0·000005 in. Therefore, manufacture of munitions to 0·005 in.—quite a liberal tolerance—necessitates tool-rooms capable of producing work accurate to ten-thousandths and possessing equipment accurate to a few hundred-thousandths of an inch. In addition to this, a reference to the metrology laboratory, with equipment accurate to millionths, is necessary.

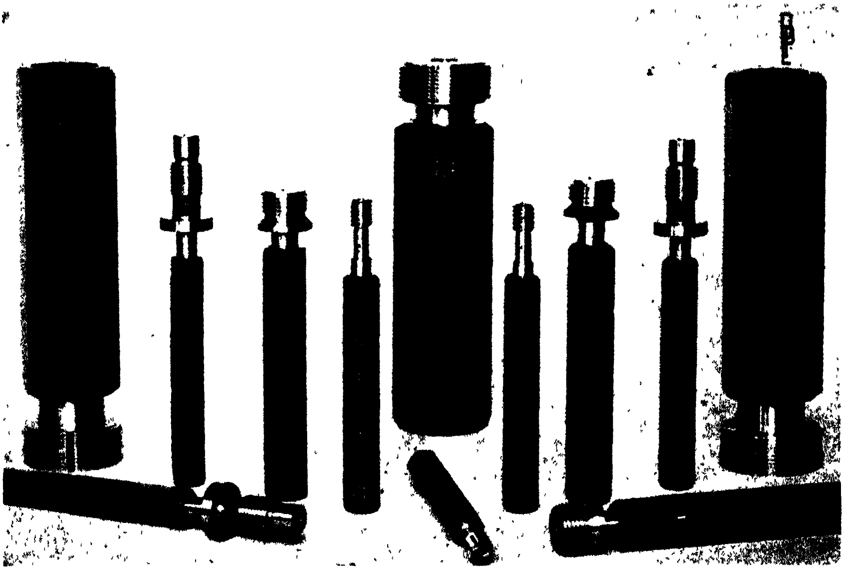

FIG. 1.—A group of thread ground limit gauges for dimensional control of tapped holes in munitions parts.

PLANT AND EQUIPMENT

It is convenient to group the operations in both tool-making and gauge-making into the following definite sections, each with its own particular type of equipment and control :—

(1) Machining of the steel in its annealed or soft form to dimensions somewhat larger than those of the finished article.
(2) Heat treatment of the machined steel to develop the hardness and toughness of the cutting edge or the wear resistance of the gauging surface.
(3) Grinding of the hardened steel to its finished size and shape.
(4) Inspection of the finished tool or gauge as to its physical properties, which may include dimensional accuracy, hardness, conformity with specification, or functional test.

Consequently, the tool-making facilities at the Dominion Physical Laboratory were planned to include :—

(1) *Machine-shop*

Here work was initiated on the steel in its soft state, and without enumerating the particular machines used it will suffice to say that a balanced set-up of bench lathes, tool-room lathes, universal milling-machines, and such subsidiary equipment as drills, bandsaw, and shaper bring the work to the next stage.

(2) *Heat-treatment*

It will readily be admitted by all those who have had tool-room experience that it is in the heat-treatment department that most tool-making troubles arise. In the machine-shop or in the grinding-room one may endeavour to make an accurate pin of diameter exactly $\frac{1}{2}$ in. As it is physically impossible to make this pin *exactly* a certain size, one specifies the dimension for its diameter as $0{\cdot}500 \pm 0{\cdot}0005$ in.—in other words, the machinist is given a tolerance of 0·0005 to which to work, and it is then possible for him to meet the requirements. In the heat-treatment of a piece of tool-steel, however, several tolerances are observed: (*a*) a hardness figure which must be maintained (*e.g.*, 62°-64° Rockwell C. scale); (*b*) a maximum dimensional change permitted (*e.g.*, a broach of length 36 in. must not be more than 0·010 out of straight when hardened); (*c*) a satisfactory crystalline and metallurgical structure.

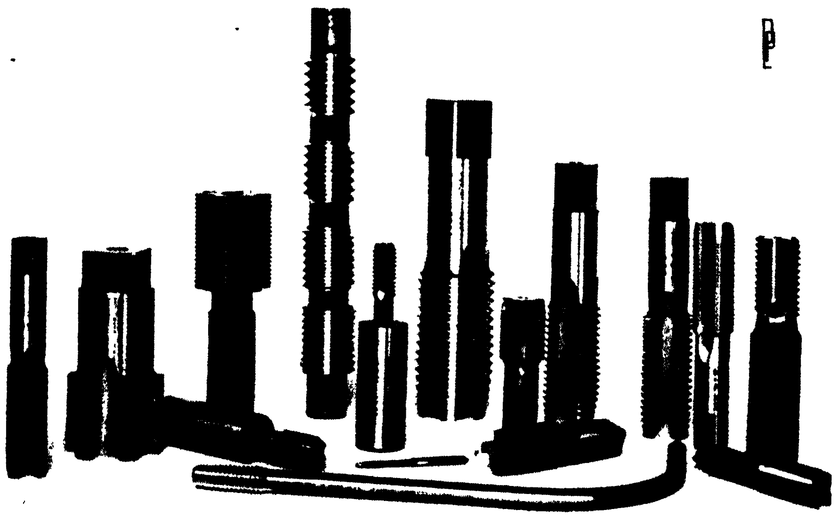

FIG. 2. Precision thread-ground machine and hand taps.

It will be appreciated, too, that the heat-treater cannot work gradually towards his specifications, but must usually attain them instantly in one sudden quench from a high temperature. Yet it is this section of a tool-room in which the least amount of control equipment exists and which usually receives least study and development. With this in view, modern electric salt baths were installed and fully automatic temperature-control equipment maintained at all stages of the work.

As this work is the subject of a separate report, it will suffice to enumerate the equipment in this section:—

Case Hardening.—Salt baths, electrically heated by the immersed electrode method.

Hardening of Tool Steels of the Straight Carbon or Alloy Type.—Hearth-type furnace, atmosphere-controlled, and electrically heated by resistance windings.

Hardening of High-speed Steels.—Salt baths electrically heated by immersed electrodes both for primary hardening and secondary hardening. A gas muffle used for preheating.

Nitriding or Cyaniding of High-speed Steels.—Electric pot furnace.
Tempering of Tool Steels.—Closed circuit air-recirculation furnace.
Stabilizing of Gauges.—Electrically heated hot-air oven.
Oil-quenching.—Quench tanks with oil cooler in circuit.
Water-quenching.—Quench tanks with circulating water.
Air-quenching.—Air blast from forced-ventilation system.

(3) *Grinding*

This section was located in a fully air-conditioned room, held at 68° F., and artificially lit by fluorescent tubes to a general intensity of 25 foot candles, with an intensity of 80 foot candles at the machines, provided by low-voltage incandescent fittings. Machines were grouped into internal and external cylindrical grinding, surface and gap grinding, tool and cutter grinding, thread grinding and lapping. A small workshop inspection-room was incorporated. Jig boring of position gauges and fixtures was also performed in this section, as it was closely associated with surface grinding and cylindrical grinding of pins and checks. In precision work it is becoming more and more generally realized that the logical procedure for the production of hardened gauges and tools should be to " rough out " in the soft, harden, and then grind to finished dimensions. New machines are consequently coming to the fore with consequent new technique. For example, the thread grinder has replaced the precision screwing-lathe with its variable lead screw and subsequent lapping to correct unpredictable dimensional changes in heat treatment. A jig grinder has just been developed which will simplify a great deal of work at present done on the jig borer and corrected after hardening.

It is evident that precision grinding, with its attendant precision measuring and control equipment, will take a larger place in all modern tool work.

(4) *Metrology*

Although the final inspection of gauges for the purpose of certification was, of necessity, separated from their manufacture, constant inspection as a means of control in the workshops was necessary at all stages. Four inspections were regularly carried out for general tool and gauge work :—

(*a*) A superficial inspection by the machine-shop foreman before passing the work to the heat-treatment room.

(*b*) A full inspection by the shop metrology-section after heat-treatment and before any grinding was done. Here hardness was checked, also straightness, superficial cracks, and such dimensions as may have been affected adversely by the hardening process.

(*c*) A further inspection by the shop metrology-section on completion of the work. It was then completely checked against the drawing and specification before leaving the shop.

(*d*) A final inspection by the metrology laboratory in the case of gauges, special tools, and precision fixtures. The article was then certified or rejected, and left the laboratory for the munitions-factory, the gauge-store, or the inspecting authority.

MANUFACTURING PROCEDURE

The scope of this article will not permit of a comprehensive description of detailed manufacturing processes for the various types of tools and gauges. It is hoped to illustrate some of the more difficult operations by describing a few special projects in which the process or the design is

thought worthy of record. In Part II a short description of staff recruitment and training for this work will also be given and a brief synopsis of the work-scheduling system, installed to secure precision production with a staff composed of a large percentage of trainees.

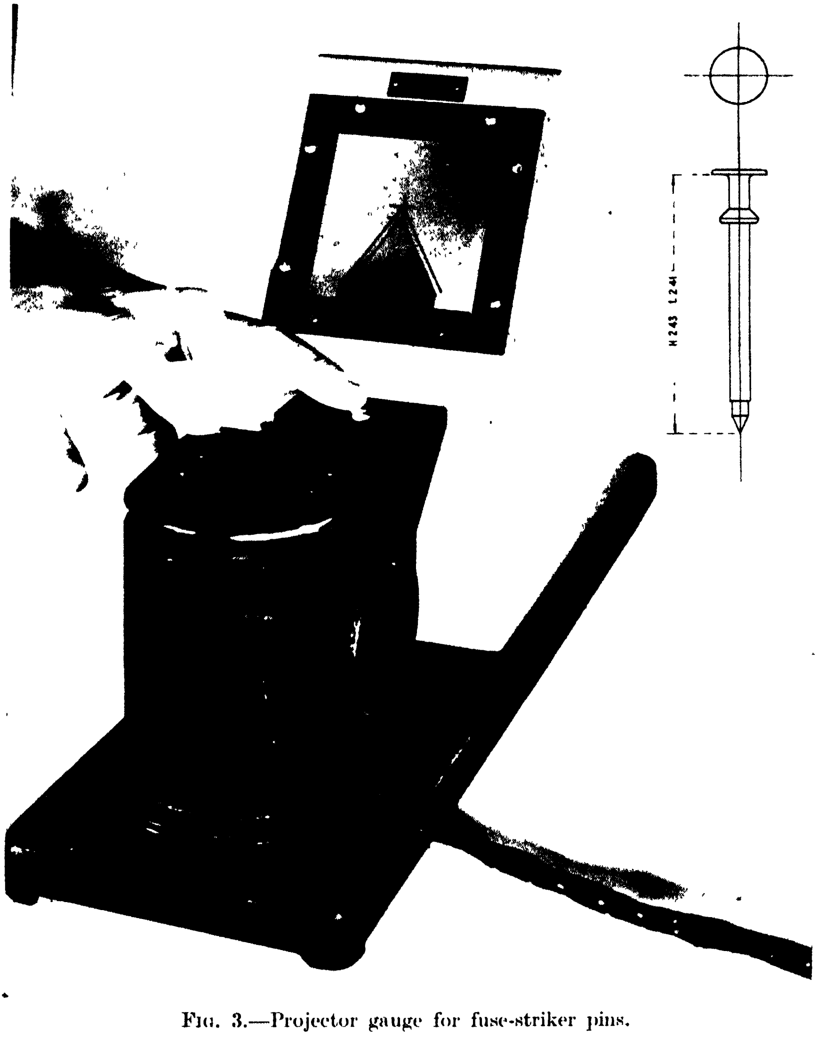

FIG. 3.—Projector gauge for fuse-striker pins.

THE PRODUCTION OF SOME SPECIAL GAUGES

(1) *Optical-Profile Projector, or "Shadowgraph," for Inspection of Fuse-striker Pin*

In order to ensure correct functioning of the fuse, the length from shoulder to point of this pin had to be controlled to 0·005 in. in a length of about 2 in. At the same time, it was convenient to gauge the shape and condition of the striker point. One form of fuse-striker pin can be seen in the foreground of the photograph (Fig. 3).

It was early found that the customary snap-gauge, or indicator gauge, damaged the point of the striker pin, especially in the hands of an unskilled operator. The optical projector-type gauge shown in Fig. 3 was therefore developed to overcome this difficulty.

The following requirements had to be considered: –

(*a*) The projectors should be as compact as possible.

(*b*) They should be readily visible in ordinary shop lighting, without the necessity for darkening the room.

(*c*) They should utilize a spectacle lens if possible, as projection lenses were difficult to obtain.

(*d*) They should be capable of adaptation to the striker pins of each of the various fuses being made in New Zealand.

(*e*) They should be easy to operate and read by an unskilled operator.

The projector, as will be seen from the photograph, consists of a cast aluminium base and lamphouse. A bracket from the base carries the projection lens, while a second bracket on the lamphouse carries in the condenser lens and the adapter necessary to hold the striker pin in position for projection.

A magnification of about 15 was found satisfactory, and this was obtained by using a lens of 1 in. focal length and a throw of about 1 ft. 3 in. For compactness and ease of observation, the image was reflected by a small mirror back to the "micro-grain" ground glass screen. This mirror was also manufactured at the laboratory by surface aluminization. A light plywood case covers the mirror and also carries the screen. On the screen the shape of the point was engraved twice – at the high limit of length for the projected striker, and also at the low limit of length. This was originally done by manufacturing an accurate setting bar, resembling a double-ended striker, one end being to the high limit of length, and the other end to the low limit. The projections of this setting bar gave the position of the screen engravings. Adjustment of the projector was subsequently carried out by means of a titling screw acting on the small mirror. The setting bar checked this adjustment.

The lamphouse carried a 6-volt 36-watt automobile-type electric bulb operated by a small transformer from 230 volts A.C., and parallel light was obtained by means of a 19 dioptre spectacle lens as a condenser. A green filter has been found to improve definition and may be used, provided the situation of the projector is such that the loss of illumination is not serious.

The striker pin was carried in a spring-loaded adapter, which ejects the pin after gauging. These adapters were removable, each variety of pin being provided with an adapter suitable for its length and form. These were interchangeable, so that the projectors themselves may be made in quantity, thus reducing the cost and time of manufacture.

With this type of optical gauge, the length of the striker, the form, and sharpness of the point may simultaneously be gauged very quickly, with the added advantage that neither the gauge nor the part being gauged will be subject to any material wear.

The projector was made from scrap aluminium and consequently was sufficiently light to be readily portable. Its cost compares favourably with the indicator-type gauge formerly used both in this country and abroad for this work, and its life should be much longer.

(2) *The Manufacture of Roller-type Screw-gauges*

One of the most serious bottlenecks in munitions production in New Zealand, in common with most countries, has been the production of screw ring-gauges in sufficient numbers and to the degree of accuracy demanded by modern interchangeable manufacture.

The difficulty of manufacture of these gauges was further accentuated by the lack of internal thread-grinding machinery and the large amount of work involved in the manufacture of equipment, both for manufacturing, controlling heat-treatment, and checking, if the alternative process of lapping was resorted to

In order to partially offset these difficulties we formulated several expedients, amongst which were—

(*a*) Split and adjustable ring-gauges.
(*b*) Caliper-type screw-gauges.
(*c*) Optical-projection screw-gauges.
(*d*) Roller- or button-type gauges.

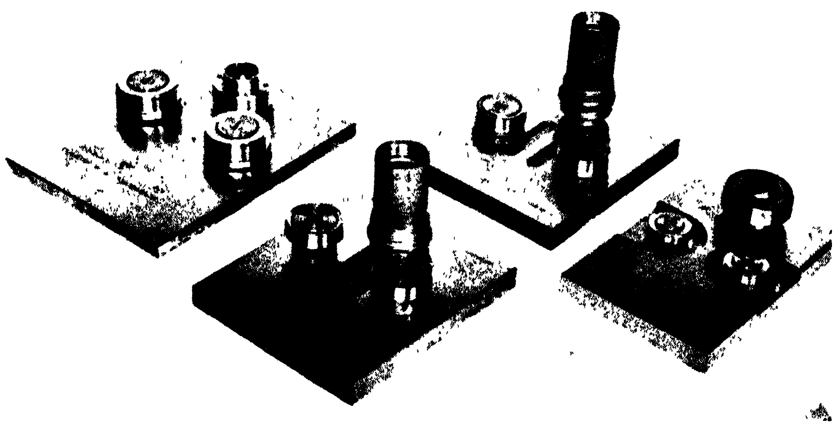

FIG. 4. -Some roller-type screw-gauges and the parts they gauge.

Of these, the first three were found to possess disadvantages either due to difficulties in manufacture to the desired accuracy or, in the case of (*c*), difficulty of use to the desired accuracy.

The roller-type screw-gauges have, however, shown considerable promise, as they possess advantages over the normal screw ring-gauge in certain respects, and seem worthy of a detailed description.

The requirements to be considered in the design of such a gauge are as follows :--

(*a*) The gauge must be capable of manufacture to such a degree of accuracy that it will be accepted by metrology on the same checks as a normal screw ring-gauge.
(*b*) The gauge shall have sufficient mechanical strength to stand up to constant use by an unskilled operator.
(*c*) The gauge shall be capable of being set to checks or a setting plug by some simple adjustment.
(*d*) The buttons shall be capable of being produced by normal external-thread-grinding machines.
(*e*) The gauge shall be of such a form that the part to be gauged can be passed across it with a satisfactory " motion cycle."

Figure 4 shows a selection of these gauges together with the parts they gauge. They consist of two thread-ground buttons of standard Whitworth form mounted on a suitable base plate. Interference due to the helix angle of the part being gauged has been avoided by making these buttons of the same effective diameter as the part being gauged, but cutting the thread

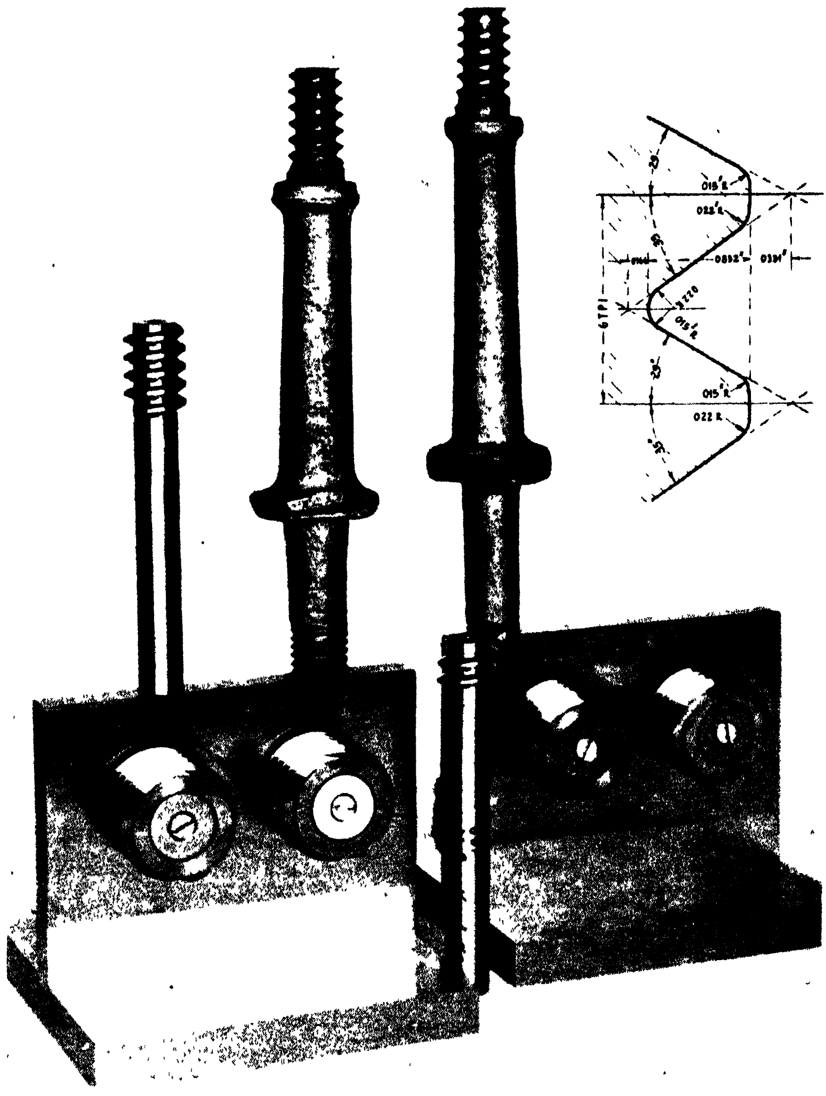

FIG. 5.—Roller-gauge for ⅝ in. insulator spindle, Cordeaux thread.

left-handed. The threads thus coincide exactly at the point of tangency between gauging button and part gauged. In order to ensure that the threads match, the rollers are each given at least one-half a pitch " end float " on their pins.

These pins have eccentric tapers on them which seat in jig-bored taper holes in a mild-steel plate. The amount of eccentricity on each was

0·010 in. and the holes were normally spaced a distance apart equal to twice the effective diameter of the part to be gauged, thus leaving 0·02 in. adjustment.

As the initial gauge was to check a part of about 2 in. diameter, the buttons necessary were rather heavy and the "feel" of the gauge in use was not sufficiently delicate. To obviate this, ¼ in. steel balls were spring-loaded against the under surfaces of the buttons, causing them to "float." This considerably increased the sensitivity of the gauge. This gauge was put into use experimentally and gauged upwards of seventy thousand fuse bodies before resetting to counteract wear.

In operation it was considerably faster and easier to use than the normal ring-gauge, and although it did not gauge roundness, this could be effected, if necessary, by a plain ring-gauge, in a second operation, such a gauge presenting no difficulty in manufacture. Subsequent gauges have been manufactured using a vertical back-plate, and these have been standardized into three series so that pins, back-plates, &c., may be manufactured in quantity, so as to assist production and reduce costs.

An interesting application of this gauge is shown in Fig. 5, where it is used to gauge the thread of a ⅝ in. telephone-insulator spindle. This thread is of Cordeaux form, and has the peculiar shape shown in outline above the insulator. Normal ring-gauges could not be produced with the grinding equipment in this country, and would require lapping, a time-consuming and uncertain process.

A button-type gauge can readily be produced by external grinding (see later paragraph on production of Cordeaux plug-gauges).

One difficulty, however, is the small diameter of the insulator spindle and the coarser pitch of the thread—six threads per inch. This would necessitate the use of a correspondingly small button with a very spindly pin through it.

Both these faults were overcome by making the buttons *twice* the pin diameter—that is, 1¼ in.—and cutting a *double start* left-hand thread on the buttons, thus ensuring the same helix angle at the effective diameter. It will be realized that the helix angle at major and minor diameters will vary slightly from those on the insulator pin, but not sufficiently to be of significance.

(3) *The Manufacture of Limit-gauges for Porcelain Insulators*

These gauges were made to the order of the Ministry of Supply for inspection and dimensional control of the type No. 1 porcelain insulator now being produced in New Zealand for local and overseas requirements. The gauges comply with B.S.S. 16 and amendments, which call for—

(*a*) A full-form "go" screw-gauge, and a truncated "not go" screw-gauge.

(*b*) A "not go" plunger-type thread core-gauge.

(*c*) A "go" thread depth-gauge.

The thread employed in the No. 1 insulator has the Cordeaux form of ⅝ in. major diameter and six threads per inch.

A diagram of the Cordeaux-thread form is shown in Fig. 5.

Owing to the unequal angles and radii at crest and root, this thread cannot be cut on a thread grinder by normal methods. Previous Cordeaux forms have been lathe cut, using a profile projector to obtain a satisfactory form, but trouble has been experienced with pitch alterations in hardening. For this reason, it was decided to attempt to grind the thread. A single-point tool was first made up by freehand grinding and stoning to match a

form diagram drawn fifty times full size. Using this tool, a circular-form tool was made, so that any further work involving the Cordeaux thread could be handled. It will be understood that the life of a circular-form tool is much greater than that of a single-point tool, and that small adjustments in form and angle can be effected by alteration in centre height or rake.

From this form tool, a crushing roll of about 3 in. diameter was made. An oil-hardened tool-steel was used for this roll, which was gashed spirally and then hardened to 64°–65° Rockwell C. A standard 220K. thread-grinding wheel was then chamfered and grooved with a roughing diamond to approximate dimensions. The formed roll was mounted on a fixture vertically above the wheel and pressed against the slowly rotating wheel, thus crushing the Cordeaux form into the periphery of the wheel. The work, which had also been roughly precut and hardened, was then mounted on

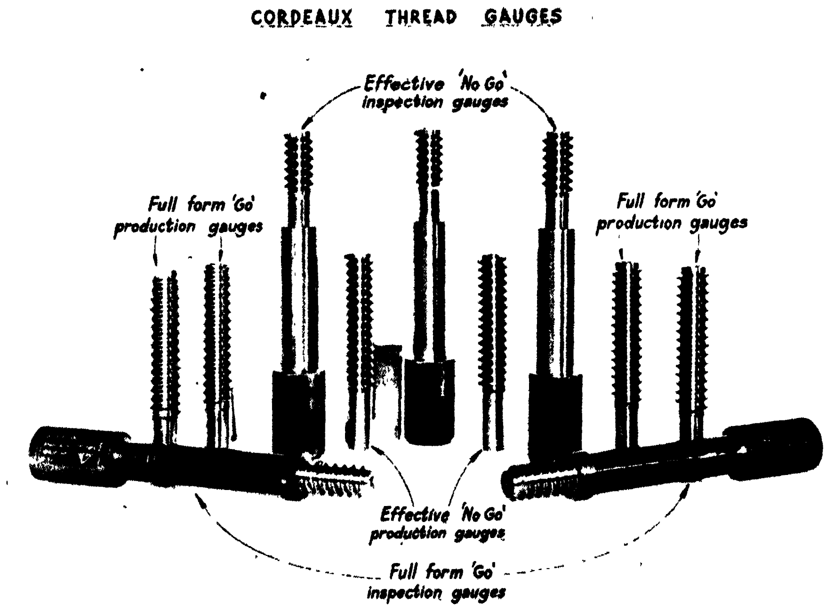

FIG. 6.—Porcelain insulator thread-gauges.

centres in the thread grinder, with the lead selected at 6-T.P.I., and grinding proceeded with, using normal cuts and wheel speeds.

The resultant gauges were most satisfactory, both as to dimensions and surface finish.

In order to obtain the truncated form necessary for the "not go" effective-diameter gauge, a full-form gauge was first ground, with its effective diameter on the high limit. A wheel was then dressed to 40° included angle and run through to clear the bottoms of the threads. It will be noticed that a shift axially is necessary here before in-feeding, as the flank angles of the Cordeaux thread are not equal. The top of the thread was truncated by cylindrical grinding so that contact was made in the neighbourhood of the effective diameter only. Finally, the end turns of thread were removed, as is standard thread form practice in screw-gauges, and in the case of the "go" screw-gauge a depth collar was ground and added.

A number of these gauges, both for production control and final inspection appear in Fig. 6.

(4) *The Production of Hardened and Ground Square-thread Gauges for 2 in. Mortar Barrel*

(*a*) *General Form of Gauges.*—Both production and inspection gauges were required, to the general form shown in Fig. 7. The major diameter was 2·315 in., four threads per inch of a square section being formed 0·125 in. wide × 0·074 in. deep. All elements to be to an accuracy of approximately 0·0003 in.

(*b*) *Soft Gauges.* As the making-up of the necessary equipment and checking gear was expected to occupy some time, soft gauges were made in tool-steel to act as temporary checks. It will be understood that, as the life of these gauges could not be expected to be much above fifty gaugings, only check or selective gauging could be carried out.

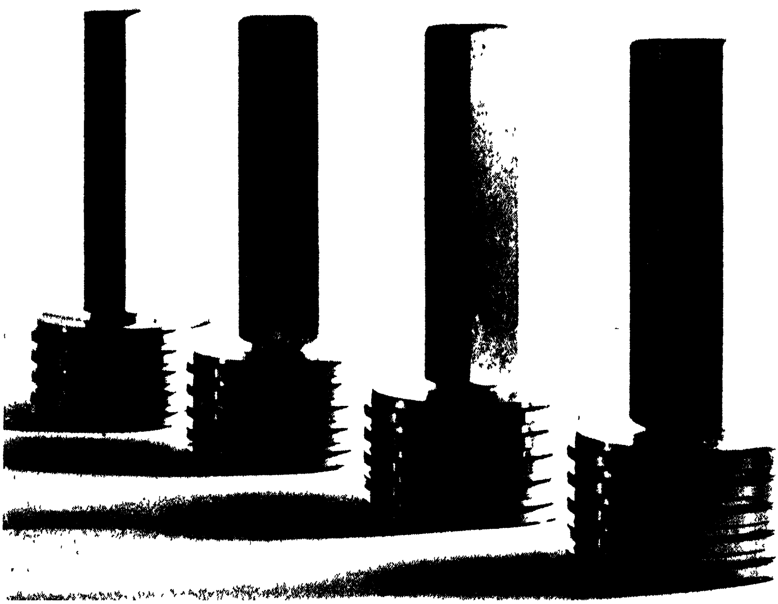

FIG. 7. -Hardened and ground square-thread plug-gauges.

(*c*) *Element-gauges.*—In order to eke out the life of the soft, full-form gauges, element-gauges were produced in the hardened state. These gauged separately, pitch, major diameter, and minor diameter, and could be produced by normal machining and grinding processes. Concentricity or correlation of the elements was then checked on a few components with the soft full-form gauges.

(*d*) *Difficulties to be overcome.*—It will be realized that the main difficulty to overcome in grinding any square thread is that of "interference." In lathe-cutting, this interference does not occur, as a single-point tool of no appreciable depth is employed. Even if inclined at the helix angle, fouling will occur at the circular path of the wheel periphery and the helical path of the groove on the work piece. In order to overcome this, the axis of the grinding wheel would have to be inclined to that of the work, in a plane at

right angles to the helix at the point of cutting. The wheel would also have to be thinned, or saucered, and each flank of the square thread ground separately.

Method of Grinding.—The machine available for the work was a Matrix 16 Universal thread-grinder. This machine permits a wheel head tilt in one plane to allow for helix angle of thread being cut. Unfortunately, there is no provision for a tilt in the second plane, nor is there any possibility of reconstructing the wheelhead to provide one without a major rebuilding of the whole head.

The first attempt to obtain the necessary relief was to set the tailstock over so that the work would make an angle of about 3° to the axis of the wheel spindle. This would have the effect of causing the machine to grind a tapered thread, so the taper-grinding attachment was set to the same figure in the opposite direction. Correction in terms of sec. 3° was then made on the pitch-correcting sine bar.

Promising results were obtained at first, but three troubles made us jettison this method. These were—

(*a*) It was almost impossible to dress the wheel accurately at right angles to the *work* axis, as all the available dressing arrangements related to the axis of the *work-table*.

(*b*) A drunkenness of pitch was experienced, which was attributed to elliptic action of the carrier dog.

(*c*) It was found that helicoidal interference still occurred slightly at 3° tilt, and this was the maximum obtainable with the above set-up.

It was thus realized that either a smaller wheel would have to be employed or a greater tilt would be necessary. A satisfactory combination of both the above was obtained by mounting on the wheelhead an auxiliary bracket carrying a tool-post grinder. This bracket was set off approximately 7½° from the axis of the existing wheel spindle.

The following precautions were taken:

(*a*) The wheelhead spindle was carefully overhauled and readjusted to obtain perfect balance and absence of end-play.

(*b*) The contacting section of the wheel was located at the height and on the axis of the helix angle adjustment, so that making one correction would not affect the other.

(*c*) The wheel was balanced and dressed from the work table axis.

Alterations to Design of Gauges.—From experience with the earlier gauges, it was decided to make slight alterations to the design of both the production and inspection gauges.

The gauge was separated from its handle, turned up from "non-shrink" tool-steel, precut, leaving an allowance of approximately 0·020 in. for hardening and grinding, and undercut on the flanks.

After hardening and stabilizing, the gauge had the surface of its end faces ground parallel, then setting-up from these faces the bore was mounted on a tapered mandrel. This mandrel was centre-lapped and driven on dead centres parallel to the work table axis. Rough grinding of each flank was then proceeded with, the mandrel being reversed on its centres for each flank.

It was possible to check the correctness of the wheel profile by examining the intersection of the ground helix with the end faces. The wheel was then redressed and finish grinding was proceeded with, using 0·0002 in. and 0·0001 in. cuts, until the cylindrical "go" check just entered the square thread. After this, pitch was checked, minor diameter ground, major diameter ground, and the edge of the thread chamfered.

In spite of the makeshift nature of the apparatus, it was found possible to keep inside the tolerances specified, the main difficulty encountered being an error in pitch occurring at 180° intervals. This manifested itself in a similar periodical alteration of the width of the square thread.

This error was later traced to eccentricity of the compound bearing on the live centre drive. This is dealt with in report No. (5), as it was during the production of the corresponding ring screw-gauges that it was finally located.

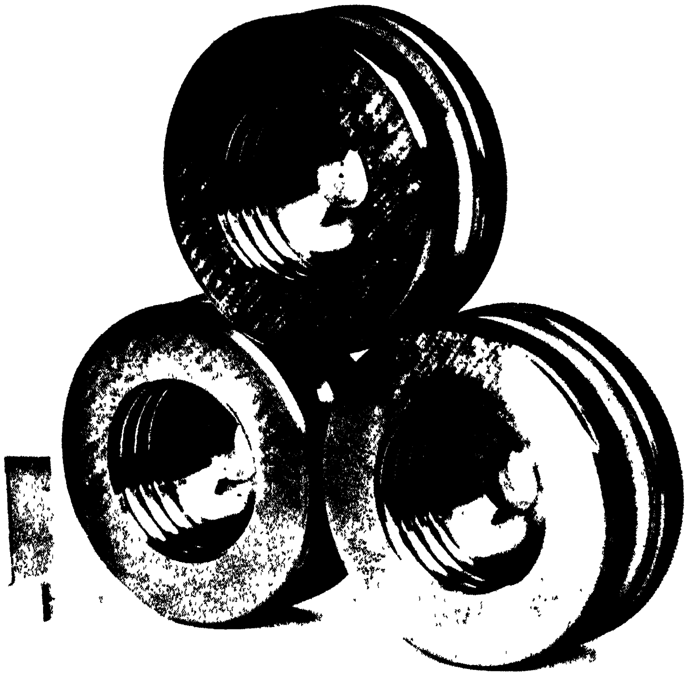

FIG. 8.—Square-thread ring-gauges, hardened and ground.

(5) *The Production of Special Square-thread Ring-gauges for Breech Piece of the 2 in. Mortar*

Encouraged by the successful production of the corresponding male gauge for the mortar barrel, it was decided to attempt to produce the square-thread ring-gauge, hardened and ground (see Fig. 8).

While the same difficulties existed as in the male gauge as regards helical interference, the following additional problems presented themselves:—

(*a*) The wheel size would require to be much smaller to allow of the internal grinding.

(*b*) Measurement could be made only by means of checks, themselves a difficult grinding job, carrying a tolerance of approximately 0·0001 in.

(*c*) Visibility was difficult, a dental mirror and "intuition" being the main aids.

(*d*) Reversal of the ring and resetting to allow of grinding each flank in turn would require considerable skill.

(*e*) The gauge required carried a concentricity check in the form of a $\frac{1}{2}$ in. end plate, on which angular position had to be engraved to indicate "start of thread." Depth of thread was also gauged from this end plate.

Method of Production.—The same machine, a Matrix 16 Universal thread-grinder, was set up for this work with the same operator. A large amount of the credit for this work must be given to the operator, and it is worthy to mention that this man was a trainee under the Wellington Technical College scheme, having had no previous experience of precision grinding or measurement before coming to the Laboratory in 1942. To the foreman of the grinding-room is due the credit for this training and also for the details of the methods described hereunder.

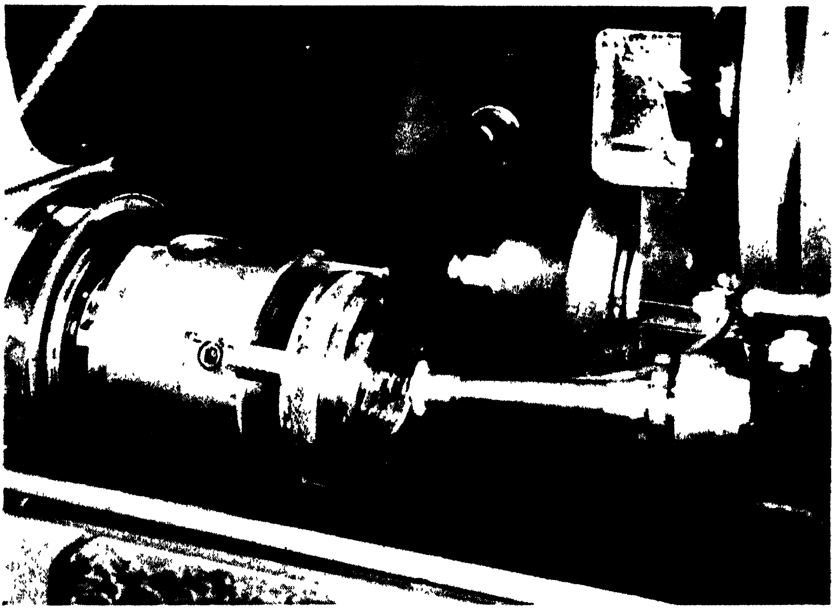

FIG. 9.—Set-up for grinding square-thread rings.

For the successful grinding of this particular gauge the following provisions are necessary :—

(*a*) Sufficient helical flank-clearance.
(*b*) Blind grinding of one flank of thread at a time.
(*c*) Thread matching the position of wheel.
(*d*) Overcoming intermittent error due to eccentricity of lay shaft and spindle of workhead (machine fault).
(*e*) Redressing flank of wheel to conform to helix axis of wheelhead.
(*f*) Ensuring concentricity of flanks when opposite flank was ground.
(*g*) Grinding half of major diameter in each setting.

As with the grinding of the square plug-gauge, a tool-post grinder was set up with the axis of the spindle at approximately 10° to that of the axis of the screw ring to allow sufficient flank clearance (see Fig. 9).

It was found that the maximum wheel diameter which could be used was 0·875 in., due to the screw helix following over the wheel. The width of wheel flank was 0·06 in. to allow grinding of one flank, and a little over half the major diameter width.

This meant grinding the flank nearest the headstock and reversing the work in the chuck to enable the opposite flank to be ground. This was accomplished by grinding both faces of the gauge parallel, and also cylindrically grinding two portions of the outside of the gauge from which to set up.

It is as well to state here that these faces required to be set up well within 0·0001 in., as the particular machine used had an amount of eccentricity of about 0·0007 in. on the chuck end, mainly due to an eccentric compound-bearing in which the live spindle ran. It was found that the dead centre drive had to be locked in one particular position before the live spindle ran true enough for setting the gauge. This, of course, caused a drunken pitch error of about 0·0008 in., which was eliminated by indexing the dead centre around the live spindle in six equal angular positions. It will be interesting to note here that this machine fault was the cause of the unsolved trouble experienced with the plug screw-gauges mentioned on p. 279, and that the leadscrew which was suspected was found to be accurate.

The flanks were ground "blind"—*i.e.*, the leadscrew was set up for right-hand grinding and the table limit switches set for left-hand grinding, while the slow return on the table was used, which meant that the wheel ground outwards from headstock to tailstock. A small dentists' mirror was used for inspecting the intersection line of flank and face of gauge, to ensure that this was truly radial. A major diameter check was previously ground which had thin flanks so that the ground portion of the major diameter could be checked for size, the amount which had to be removed being carefully checked beforehand.

An adjustment was incorporated to enable the working flanks of the wheel to be aligned over the axial helix centre line of the wheelhead after each dressing. The wheel used was an aluminium oxide 60 K5BE. The spindle speed was 9,000 r.p.m. and work speed for finishing and roughing 498 r.p.m. Roughing cuts were from 0·001 in. to 0·0005 in. and finishing cuts no more than 0·0001 in. The coolant used was Cut-max 20–40 straight, the flow for roughing being 4 gallons per minute while for finishing cuts the supply was dispensed with.

The floor-to-floor time for each gauge was twelve hours. This considering the temporary nature of the set up and the difficulties to be overcome, was thought satisfactory and the cost of production of these gauges justified, by comparison with the increased life obtained over the original soft-gauges.

As in the case of the male gauges for the mortar barrel, it was necessary to provide control of the process while these hardened gauges were being developed, and this was done as follows:—

(*a*) By the manufacture of soft full-form gauges, using a formed threading-tool in the Bryant and Symons precision internal screwing-lathe.

(*b*) By the separate gauging for the elements with hardened element gauges.

These could be used for the main gauging processes, and the correlation, or concentricity, of the elements checked by the occasional use of a soft full form gauge.

The foregoing examples illustrate a few of the more difficult problems encountered in the production of gauges. It is hoped in Part II of this article to deal with the production of certain precision tools and also to touch briefly on the procedure adopted for the training of unskilled staff for this work, and on the method adopted for routing the work from machine to machine through the tool-room.

(To be concluded)

THE EFFECT OF DAIRY FACTORY DRAINAGE UPON THE QUALITY OF STREAMS IN TARANAKI*

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Summary

Chemical and bacteriological analyses were made during 1939–40 of waters from two streams in Taranaki, the samples being taken just above, and at a point 100 yards below, the point of discharge of dairy factory effluent. Where the dilution was small (Waihi Stream), the analyses showed an appreciable degree of contamination of the water by the factory drainage. Where the dilution was considerable (Waingongoro Stream), the effect of the drainage on the water was not appreciable.

During 1940–41, samples were taken for analysis from four streams, at half-hour intervals throughout the day, at points above the discharge and some distance below the discharge, with a view to establishing the distance to which the effect of the drainage discharge extended downstream.

In the Waihi Stream, with a dilution of only 1 in 100, the effect of the drainage was evident at 2 miles, and did not completely disappear until approximately 3½ miles, below the drainage outfall.

In the Tawhiti, with a dilution of 1 in 1,224, the effect of the drainage had disappeared at 1½ miles.

In the Kapuni, with a dilution of not less than 1 in 3,560, there was only the barest effect at 100 yards, and all evidence of the factory drainage had disappeared at 400 yards, below the outfall.

The Kaupokonui gave a specially rapid recovery. The dilution was 1 in 5,515, and all evidence of the drainage from two factories within 300 yards of each other had disappeared at 400 yards below the outfall from the second factory.

The results therefore show that with reasonable dilution available the discharge of dairy-factory drainage into a well-oxygenated stream has only a temporary effect on the quality of the water.

THE composition of drainage waters from both butter and cheese factories has been shown in a previous paper(1) to be such as to affect appreciably the quality of the waters in streams with small dilution capacity. The effect of drainage waters on a stream, and the rate of purification of these waters by a stream, depend not only on the strength of the contaminating effluent and on the degree of dilution available, but also on the type of stream-bed and the rate of flow, which control the degree of reoxygenation of the water. The present investigation records a study of the effect of the discharge of dairy factory drainage waters on the composition and general quality of the water of the stream at the point of discharge and for some distance down the stream. It thus provides data for an appreciation of the extent and the persistence of the pollution, if any, of the stream through the discharge of the effluent. For this purpose samples of water were taken above and below the factory drainage outlet, and these were examined both bacteriologically and chemically. A preliminary investigation of two streams—

* Investigation carried out at request of Dairy Research Institute (N.Z.), Department of Scientific and Industrial Research, Palmerston North, and with the aid of funds provided by the Institute.

viz., the Waihi and the Waingongoro—was made in the 1939-40 season, and a more extensive investigation of four streams—viz., the Waihi, the Tawhiti, the Kapuni, and the Kaupokonui—was made in 1940–41.

1939–40 INVESTIGATION

The two streams selected were very different in character. The Waihi Stream, on the one hand, is extremely small and, although marked on the map, is little more than a ditch for many miles of its course, and in drought conditions becomes reduced to a flow of about 10 gallons per second. The factory which drains into it is a dual-plant factory with an annual production of 600 tons of butter and 600 tons of cheese, so that the proportion of volume of drainage to volume of flow and the degree of contamination are relatively high and would probably represent the maximum contamination to be encountered from dairy effluents in Taranaki. The Waingongoro Stream, on the other hand, is broad, rapid-flowing, moderately shallow, and stony, and is one of the best trout streams in Taranaki. It rises from the snows of Mount Egmont and pursues a long and sinuous course, the flow being everywhere very rapid and the water well oxygenated. In drought conditions the volume of water is considerably reduced, but was never observed at less than 1,250 gallons per second, and this was a record low level. In winter the flow is much greater, but the stream is never navigable on account of the numerous rapids and shallows. Although the factory discharging drainage into it is a cheese factory with an annual production of about 600 tons, the dilution is so great that the influence of the drainage on the quality of the waters could be expected to be very slight and to represent about the minimum likely to occur.

SAMPLING AND ANALYSIS

Both streams were sampled just above the point of inflow of factory drainage and at about 100 yards below this point, and, in the case of the Waingongoro, close to the same bank. Sampling took place always in the afternoon, about the midflow of the drainage from the afternoon wash-up of vats, utensils, floors, and press drainings. (Investigation has already shown that this is the most concentrated portion of the day's drainage from a cheese factory.)

The tests selected were—

(1) Presumptive coliform tests at dilutions down to 0·001 ml.
(2) Agar bacterial count at 32° F.
(3) Gelatine bacterial count at 22° C.
(4) Total solids by evaporation of 20 ml.
(5) Nitrogen as free and saline ammonia.
(6) Nitrogen as albuminoid ammonia.
(7) Oxygen absorbed from permanganate in four hours at 70° F.
(8) Dissolved oxygen immediately, and in one day, two days, and five days.

The results for tests (4), (5), (6), and (7) are expressed as parts per hundred thousand. The results for dissolved oxygen (8) are expressed as parts per million.

The bacteriological results for the Waihi Stream above and below the outlet are shown in Table I, and the chemical results in Table II. The corresponding results for the Waingongoro Stream are given in Tables III and IV.

TABLE I.—RESULTS OF BACTERIOLOGICAL ANALYSIS OF WATERS FROM WAIHI STREAM ABOVE AND 100 YARDS BELOW DRAINAGE OUTLET OF CHEESE AND BUTTER FACTORY

Date.	Presence of Coliform Organisms × 10.								Bacterial Counts per Millilitre.				Remarks.
	Above Outlet.				Below Outlet.				Agar.		Gelatine.		
	0.	−1.	−2.	−3.	0.	−1.	−2.	−3	Above Outlet	Below Outlet.	Above Outlet.	Below Outlet.	
1939													
November 8	+	−	−	−	+	+	+	+	190	41,000	5,600	150,400	..
„ 16	+	+	−	−	..	..	..	..	190	24,000	8,000	Uncountable	..
„ 23	+	+	+	−	..	..	..	..	1,040	121,000	2,100	62,000	First fine weather after continua rain.
December 8	+	+	+	−	..	..	..	..	2,920	904,000	14,400	1,856,000	..
„ 14	+	+	+	−	..	..	..	..	4,040	156,000	7,200	192,000	Flood forty-eight hours before.
„ 21	+	+	−	−	..	..	..	..	810	264,000	7,700	760,000	Hot spell. River again very low
1940													
January 9	+	+	+	−	..	..	..	..	1,360,000	17,920,000	Uncountable	Uncountable	Flow, 26 g/s*; low and dis coloured; bad smell belov outlet.
„ 18	+	+	−	−	..	..	..	..	200,000	..	576,000	..	28 g/s; dry spell; bad smel below outlet.
February 1	+	+	−	−	..	..	..	..	100	63,000	1,000	72,000	31 g/s; after flood.
„ 14	+	+	−	−	..	..	..	..	2,200	..	3,600	..	50 g/s; fortnight flood.
„ 22	+	+	+	−	..	..	..	..	700	178,000	5,100	416,000	31 g/s; fine weather.
March 6	+	+	−	−	..	..	..	..	2,100	528,000	6,400	972,000	56 g/s; after floods.
„ 14	+	+	−	−	..	..	..	..	1,200	62,000	3,800	52,000	26 g/s; fine weather.
„ 20	+	+	−	−	..	..	..	..	2,100	404,000	4,500	456,000	26 g/s; fine week.
„ 27	+	+	−	−	..	..	..	..	1,700	524,000	5,200	840,000	28 g/s; fine week; milky anc discoloured below outlet.
April 4	+	+	−	−	..	..	..	..	200	364,000	4,000	Uncountable	9 g/s; record low level; bac smell below outlet.
„ 11	+	+	−	−	..	..	..	..	300	59,000	37,200	524,000	38 g/s; heavy rain durin week.
„ 24	+	+	−	−	..	..	..	..	900	104,000	4,480	364,000	19 g/s.
September 6	+	+	−	−	..	..	..	..	1,285	42,000	Uncountable	..	56 g/s.

* Gallons per second.

TABLE II.—RESULTS OF CHEMICAL ANALYSIS OF WATERS FROM WAIHI STREAM ABOVE AND 100 YARDS BELOW DRAINAGE OUTLET OF CHEESE AND BUTTER FACTORY

Date.	Total Solids (Parts per 100,000).		Nitrogen: F. and S (Parts per 100,000)		Nitrogen: A A (Parts per 100,000)		O_2 absorbed from $KMnO_4$ Four Hours at 70° (Parts per 100,000).		Dissolved O_2 per 10^6.							
									Immediate		One Day		Two Days.		Five Days.	
	Above.	Below.	Above.	Below.	Above	Below	Above.	Below	Above	Below	Above.	Below.	Above.	Below.	Above.	Below.
1939																
November 8 ..	18·4	21·1	0·010	0·016	0·063	0·074	0·183	0·254	7·3	4·9	6·8	Nil	6·2	..	5·4	..
„ 16 ..	20·7	21·9	0·014	0·023	0·020	0·067	0·187	0·485	7·4	4·2	7·1	Nil	6·7	..	6·0	..
„ 23 ..	16·0	19·7	0·008	0·016	0·021	0·050	0·244	0·351	7·0	3·7	6·8	Nil	5·9	..	5·1	..
December 8 ..	23·6	29·4	0·021	0·029	0·033	0·111	0·234	0·500	7·6	2·2	7·0	..	6·5	..	..	..
„ 14 ..	14·2	16·3	0·006	0·007	0·026	0·043	0·315	0·362	6·2	4·6	6·1	0·7	6·0	0·1	5·1	Nil
„ 21 ..	19·5	25·2	0·008	0·020	0·026	0·074	0·113	0·391	5·2	1·8	4·7	Nil	4·4	..	3·9	..
1940																
January 9 ..	31·6	44·7	0·020	0·118	0·055	0·216	0·206	0·709	4·4	1·4	4·0	Nil	2·8	..	2·5	..
„ 18 ..	19·1	37·1	0·006	0·009	0·026	0·143	0·249	0·743	5·0	2·2	4·9	Nil	4·2	..	3·7	..
February 1 ..	15·11	21·2	0·006	0·017	0·020	0·031	0·186	0·228	6·8	4·3	6·5	1·3	6·4	0·4	5·3	Nil
„ 14 ..	18·2	..	0·007	..	0·027	..	0·188	..	8·1	..	7·8	..	7·7	..	6·2	..
„ 22 ..	25·2	31·0	0·006	0·047	0·020	0·077	0·209	0·713	6·8	3·1	6·5	Nil	6·3	..	5·4	..
March 6 ..	17·9	19·3	0·006	0·016	0·024	0·125	0·198	0·562	7·8	5·0	7·7	Nil	6·8	..	6·8	..
„ 14 ..	17·0	19·7	0·008	0·010	0·032	0·045	0·148	0·216	8·5	5·8	8·0	1·8	7·9	Nil	6·6	..
„ 20 ..	17·5	22·2	0·007	0·009	0·024	0·090	0·154	0·313	8·3	5·6	8·0	Nil	7·4	..	7·1	..
„ 27 ..	20·1	56·1	0·009	0·169	0·026	0·333	0·185	1·95	8·2	3·0	7·8	Nil	7·6	..	7·0	..
April 4 ..	23·3	33·7	0·007	0·012	0·012	0·133	0·136	0·688	8·6	5·0	8·6	Nil	7·6	..	7·4	..
„ 11 ..	18·3	25·8	0·009	0·143	0·021	0·289	0·147	0·271	8·9	6·7	8·5	0·7	8·5	Nil	8·1	..
„ 24 ..	16·1	22·6	0·008	0·180	0·025	0·295	0·083	0·272	9·1	7·7	8·9	1·0	8·6	Nil	7·9	..
September 6 ..	14·9	19·9	0·010	0·198	0·018	0·310	0·121	0·209	9·6	8·4	9·2	Nil	9·1	..	8·6	..

TABLE III.—RESULTS OF BACTERIOLOGICAL ANALYSIS OF WATERS FROM WAINGONGORO STREAM ABOVE AND 100 YARDS BELOW DRAINAGE OUTLET OF CHEESE FACTORY

Date.		Presence of Coliform Organisms × 10.								Bacterial Counts per Millilitre.				Remarks.
		Above Outlet.				Below Outlet.				Agar.		Gelatine.		
		0.	−1.	−2.	−3.	0.	−1.	−2.	−3.	Above Outlet.	Below Outlet	Above Outlet.	Below Outlet	
1939														
November	8	+	−	−	−	+	+	−	−	100	590	8,960	24,480	..
”	16	+	+	−	−	+	+	+	−	120	24,640	6,500	..	..
”	23	+	+	−	−	+	+	+	−	1,210	7,100	4,700	17,000	First fine weather after heavy rain.
December	8	+	+	−	−	−	−	+	−	1,620	12,320	16,800	83,200	Hot, dry weather.
”	14	+	+	+	−	+	−	+	−	3,760	4,720	18,200	21,600	Fine weather; flood 48 hours previously.
”	21	+	+	−	−	+	+	−	−	12,560	15,280	36,800	41,600	Fine spell.
1940														
January	9	+	+	−	−	+	+	−	−	1,824,000	2,240,000	11,200	49,600	1,250 g/s.*
”	18	+	+	−	−	+	+	−	−	..	..	128,000	800,000	..
February	1	+	+	−	−	+	+	−	−	500	1,200	3,000	6,000	3,750 g/s; flood conditions.
”	14	+	+	−	−	+	+	−	−	1,700	252,800	7,600	136,000	4,687 g/s; flood.
”	22	+	+	−	−	+	+	−	−	2,700	8,200	25,600	36,800	2,250 g/s.
March	6	+	+	−	−	+	+	−	−	2,500	4,400	8,000	9,600	3,828 g/s; flood.
”	14	+	+	−	−	+	+	−	−	700	3,600	8,200	36,800	2,812 g/s.
”	20	+	+	−	−	+	+	−	−	2,600	4,500	14,300	26,000	2,447 g/s.
”	27	+	−	−	−	+	+	−	−	500	5,300	3,800	7,800	1,530 g/s.
April	4	+	−	−	−	+	+	−	−	2,700	14,800	..	..	7,250 g/s; record low level.
”	11	+	+	−	−	+	+	−	−	600	8,700	36,400	54,000	1,720 g/s.
”	24	+	+	−	−	+	+	−	−	600	3,100	3,280	12,700	1,250 g/s; very low again.
September	6	+	+	+	−	+	+	+	−	2,500	6,350	14,400	24,800	4,700 g/s.

* Gallons per second

TABLE IV.—RESULTS OF CHEMICAL ANALYSIS OF WATERS FROM WAINGONGORO STREAM ABOVE AND 100 YARDS BELOW DRAINAGE OUTLET OF CHEESE FACTORY

Date.		Total Solids (Parts per 100,000).		Nitrogen. F and S. (Parts per 100 000).		Nitrogen · A A (Parts per 100 000)		O_2 absorbed from $KMnO_4$ Four Hours at 70 (Parts per 100 000)		Dissolved O_2 per 10^6.							
										Immediate.		One Day.		Two Days.		Five Days.	
		Above.	Below.	Above.	Below.	Above.	Below.	Above.	Below.	Above.	Below.	Above.	Below	Above.	Below.	Above.	Below.
1939																	
November 8	..	14·5	17·1	0·007	0·009	0·029	0·041	0·141	0·152	9·8	9·6	9·4	8·6	8·4	7·4	8·0	6·8
„ 16	..	17·0	19·0	0·012	0·013	0·020	0·023	0·129	0·144	9·8	9·6	9·4	8·5	8·6	6·3	8·1	5·8
„ 23	..	13·1	14·0	0·007	0·009	0·020	0·023	0·175	0·195	9·4	9·4	9·1	8·2	8·6	7·8	8·0	7·1
December 8	..	12·7	13·5	0·009	0·010	0·029	0·034	0·297	0·343	9·1	9·0	8·6	8·0	8·2	7·2	8·0	..
„ 14	..	7·1	7·9	0·002	0·003	0·013	0·016	0·059	0·113	8·0	9·1	7·6	8·7	7·4	7·7	7·3	6·6
„ 21	..	10·6	12·4	0·005	0·007	0·020	0·021	0·092	0·141	8·8	8·0	8·4	7·4	7·4	6·9	7·3	6·5
1940																	
January 9	..	14·7	14·8	0·006	0·007	0·024	0·034	0·129	0·171	8·8	8·7	8·4	8·2	7·4	6·8	7·3	2·8
„ 18	..	12·2	13·4	0·006	0·007	0·017	0·027	0·131	0·172	8·5	8·4	8·2	6·4	7·8	4·4	6·2	2·4
February 1	..	..	..	0·003	0·003	0·007	0·010	0·066	0·066	9·4	9·4	8·9	9·0	8·7	8·4	8·7	8·1
„ 14	..	12·6	12·9	0·004	0·005	0·014	0·017	0·115	0·132	10·6	10·4	10·2	9·3	9·8	9·1	8·5	7·7
„ 22	..	12·9	14·0	0·007	0·007	0·016	0·016	0·110	0·128	10·3	10·1	9·9	8·5	9·4	6·8	8·8	4·5
March 6	..	10·4	10·8	0·003	0·013	0·016	0·017	0·106	0·126	11·1	10·7	10·7	10·3	10·6	9·8	9·0	8·9
„ 14	..	8·9	12·1	0·006	0·008	0·024	0·027	0·076	0·115	11·2	10·1	10·8	8·9	10·4	5·7	9·5	0·4
„ 20	..	11·0	11·5	0·004	0·005	0·018	0·025	0·090	0·122	11·6	11·4	11·0	10·3	10·1	9·7	9·9	8·0
„ 27	..	13·7	14·2	0·005	0·008	0·018	0·021	0·113	0·123	11·4	11·0	10·4	10·0	10·3	9·0	9·6	7·6
April 4	..	17·2	17·5	0·004	0·007	0·011	0·014	0·012	0·013	11·8	11·8	11·3	9·2	10·7	7·8	10·2	5·2
„ 11	..	14·2	17·7	0·008	0·010	0·020	0·029	0·162	0·173	11·0	11·0	10·6	8·9	10·0	8·3	9·2	6·4
„ 24	..	13·1	13·6	0·007	0·008	0·010	0·010	0·111	0·120	12·4	12·4	11·8	11·1	11·1	10·4	9·5	8·5
September 6	..	14·3	14·4	0·009	0·010	0·012	0·017	0·187	0·270	11·3	10·5	..	..	8·1	6·8	7·3	6·4

The Waihi Stream rises in swamp land and is fed by springs which flow from hillside pasture lands. Stock have free access to it, and thus its initial quality is never very high. It is subject to large changes in quality due to weather variations and to movements of stock. Its worst general analysis came early in January and seemed to be connected with disturbances caused by stock. At its record low level on 4th April the water was organically almost at its best, but had an abnormally high content of saline matter.

The effect of the dairy drainage upon the Waihi Stream was always very marked to the senses. The water was invariably opalescent and offensive. Grey fungus replaced green algæ in the stream-bed. Suspended particles were common. These changes were reflected in the bacterial counts, the coliform tests, and in the values for total solids and for biochemical oxygen demand. It was rare for this contaminated water to retain any dissolved oxygen after twenty-four hours. The nitrogen figures and the absorption of oxygen from permanganate were always higher than for the uncontaminated water, but the changes were not so pronounced as might have been expected. The greatest degree of contamination occurred on 9th and 18th January not when the stream was at its lowest for the season, but when the original quality of the stream (particularly in bacterial count and dissolved oxygen content) was at its worst.

The water of the Waingongoro Stream, taken before entry of the dairy factory drainage, gave almost always a positive test for coliform contamination in $\frac{1}{10}$ ml. and showed other evidence of its passage through heavily stocked farm lands. Its greatest contrast with the Waihi lay in its content of dissolved oxygen, which was always very high. Its freedom from decomposable organic matter was shown by its high residual dissolved oxygen content after five days of storage—a figure which generally exceeded the original oxygen content of the water of the Waihi. Here, again, the analytical figures showing high contamination did not always occur at times of low stream levels—indeed, at the record low level on 4th April the only abnormal feature was a high content of saline matter.

It is not surprising that such a highly oxygenated water suffered very little in quality from the dairy drainage it received (see Tables III and IV). The increases in total solids content are scarcely significant, while the ammonia contents of the water below the inflow do not exceed those for the Waihi Stream above the inflow of dairy factory drainage. The only chemical determination which gave any indication comparable with the bacteriological tests was the value for biochemical oxygen demand. The results for the Waingongoro Stream would indicate that dairy drainage, properly free of fat and gross solids and containing no whey (as was the case), is practically harmless and undetectable in a well-oxygenated stream of reasonable size.

RESEARCH DURING 1940–41

The results detailed above cannot be accepted as giving a satisfactory picture of the effect of dairy drainage on natural waters, for the following reasons :—

(1) Only two streams were investigated, and these were of the two extreme types.

(2) The streams were sampled only at two places, and always at the same times, and the results therefore are not representative of the average quality during the period of discharge of drainage.

(3) No attempt was made to trace the drainage downstream and to find where its effect on the composition of the water in the stream ceased to be evident.

The work undertaken in 1940–41 was designed to cover these deficiencies. Four streams were investigated, viz. :—

(*a*) The Waihi.

(*b*) The Tawhiti, a small stream by most standards but considerably larger than the Waihi.

(*c*) The Kapuni River.

(*d*) The Kaupokonui River.

These four streams represent all types common in Taranaki, ranging from the smallest, where contamination with dairy effluent is obvious to sight and smell, to the largest, where the contamination is so slight as scarcely to affect the analytical results.

The following general procedure was adopted :—

(1) Each selected stream was first "surveyed" by a number of field tests for dissolved oxygen until a point was established down-stream where the composition had returned to normal.

(2) On subsequent dates throughout December, January, and February the streams were sampled regularly, generally once each half-hour throughout the working day of the factory, at this point and also above the discharge point. Intermediate points were also selected on occasions.

(3) The same tests were completed upon each sample as in the 1939–40 schedule, but immediate dissolved oxygen tests were made in the field, and the tests for oxygen absorption from permanganate were for three minutes' heating at 100° C. instead of for four hours at 70° C. The former results are again expressed as parts per million, and the latter as parts per hundred thousand.

(4) Observations were made on temperatures of air and water ; and data were collected on volume of stream flow and of drainage so that variations could be studied.

(*a*) THE WAIHI STREAM

This stream was included again as it was thought that the persistence of the effect of drainage discharge into such a small stream would represent a maximum. The results of the first survey, made on 16th December (see Table V), show that there was a marked contamination down-stream for

TABLE V.—RESULTS OF ANALYSES OF SAMPLES OF WATER FROM WAIHI STREAM AT VARIOUS DISTANCES BELOW FACTORY DRAINAGE OUTFLOW

(Samples taken in fine weather following continued dry spell; shade air temperature, 72 F.)

Sample No.	Distance from Factory Drainage Outflow.	O_2 absorbed from Permanganate in Three Minutes at 100 C. (Parts per 100,000).	Dissolved O_2 per 10^6. Immediate.	Dissolved O_2 per 10^6. After Five Days at 70° F.
1	Above drainage	0·49	6·7	4·0
2	100 yards below	1·28	3·7	Nil
3	350 yards below	1·12	2·0	Nil
4	700 yards below	1·06	1·4	0·1
5	1 mile below	0·80	1·4	0·1
6	1¾ miles below	0·94	2·4	0·2
7	2¼ miles below	0·45	5·2	0·4
8	3½ miles below	0·42	6·3	5·7
9	3¾ miles below (above race) ..	0·40	6·4	6·2
10	3¾ miles below (below waterfall)	0·37	8·2	6·4

about 2¼ miles. Thereafter improvement was rapid, and from the 3¼-mile point onward the water had returned to a quality equal to that above the factory drainage outflow, as confirmed by the more detailed analyses of samples 1 and 9 given in Table VI :—

TABLE VI.—DETAILED ANALYSES OF SAMPLES 1 AND 9 (TABLE V)

Analytical Test.	Sample No. 1: Above Factory.	Sample No. 9: 3¼ Miles below Factory.
Agar count per millilitre	1,250	2,720
Gelatine count per millilitre	6,100	9,880
Total solids per 10^5	17·48	13·21
N_2 as free and saline ammonia per 10^5	0·0088	0·0095
N_2 as albuminoid ammonia per 10^5	0·0256	0·0284
O_2 absorbed from permanganate in three minutes at 100° C. per 10^5	0·49	0·40
Dissolved O_2 per 10^6—		
(1) Immediate	6·7	6·8
(2) After one day at 70° F.	6·4	6·6
(3) After two days at 70° F.	5·9	6·5
(4) After five days at 70° F.	4·0	6·2

A second survey, on 17th December, under similar weather conditions confirmed that the contamination remained evident for a distance of 2 miles, that recovery was then rapid, and was practically complete at 3 miles from the outflow.

The Waihi receives waters from several small tributary streams at various distances below the factory. They are all very small, with flows not exceeding 7 gallons per second, and all come from hillside soakages or small springs.

Results for the waters of these tributaries are given in Table VII :—

TABLE VII.—ANALYTICAL VALUES FOR WATERS OF TRIBUTARIES OF WAIHI STREAM, 17TH DECEMBER

Tributary No.	Distance below Factory.	O_2 absorbed from Permanganate in Three Minutes at 100° C. (Parts per 100,000).	Dissolved O_2 per 10^6.	
			Immediate.	After Five Days at 70° F.
1	900 yards	0·64	8·4	2·8
2	1¼ miles	0·20	8·9	6·4
3	1¾ miles	0·69	6·9	4·9
4	2½ miles	0·39	7·6	6·7

There was evidently some organic matter in tributaries 1 and 3. The other two were much purer than the original Waihi. All tributaries were well oxygenated and, except for No. 1, held their oxygen well on storage. These contributing streams would certainly reduce the time and distance of recovery of the main stream.

Results of further surveys, made on 20th December and 25th January, are given in Table VIII. On 20th December the weather was still fine and warm with a shade and water temperature of 69° F. The stream was very discoloured with drainage, and there was a foul odour around the outfall and to about 600 yards below it. The 25th January was a fine clear day after overnight rain, air temperature 73° F., water temperature 69° F.

The effects of the factory drainage did not extend so far down-stream as usual, probably due to the overnight rain, which had swelled the flow to about 48 gallons per second.

TABLE VIII.—RESULTS OF ANALYSES OF WATERS FROM WAIHI STREAM, 20TH DECEMBER AND 25TH JANUARY

Sample No.	Distance from Factory Drainage Outflow.	O_2 absorbed from Permanganate in Three Minutes at 100° C (Parts per 100,000).		Dissolved O_2 per 10^6.			
				Immediate.		After Five Days at 70° F.	
		20th December.	25th January	20th December	25th January	20th December	25th January.
1	Above ..	0·42	0·49	6·9	6·5	4·4	5·5
2	100 yards below..	0·78	0·70	4·0	2·1	Nil	Nil
3	600 yards below..	0·83	0·80	0·7	1·2	Nil	Nil
4	1 mile below ..	0·42	0·70	1·4	3·1	0·1	0·8
5	2 miles below ..	0·62	0·58	2·6	3·4	0·2	1·6
6	2¾ miles below ..	0·40	0·52	4·5	4·1	3·2	3·9
7	3½ miles below ..	0·39	0·41	6·3	6·0	4·7	4·9

The analyses show, however, that contamination was still present two miles down-stream from the point of drainage discharge. The results in Table IX show that the water had returned to normal at 3½ miles below the outfall.

TABLE IX.—DETAILED ANALYSES OF SAMPLES 1 AND 7 (TABLE VIII), WAIHI STREAM, 25TH JANUARY

Test.	Sample No. 1 Above Drainage Outflow.	Sample No. 7 3½ Miles below Drainage Outflow.
Agar count, per millilitre	1,800	3,700
Gelatine count, per millilitre	2,300	6,900
Coliform test (limit)	+ in $\frac{1}{10}$	+ in $\frac{1}{10}$
Total solids per 10^5	19·60	20·0
N_2 as free and saline ammonia per 10^5	0·0071	0·0083
N_2 as albuminoid ammonia per 10^5	0·0242	0·0256
O_2 absorbed from permanganate in three minutes at 100° C. per 10^5	0·49	0·41
Dissolved oxygen per 10^6—		
(1) Immediate	6·5	6·0
(2) After one day at 70° F.	6·0	5·9
(3) After two days at 70° F.	5·9	5·7
(4) After seven days at 70° F.	5·5	4·9

Relationship of Volume of Drainage to Flow of Waihi Stream

During the month of December the factory draining into the Waihi manufactured, on the average, 7,250 lb. of cheese daily and 5,740 lb. of creamery and whey butter. Allowing drainage for these at rates previously found(1) per pound of cheese and butter—viz., 0·84 gallons per pound of cheese and 1·00 gallons per pound of butter—with due regard to output, we arrive at 11,838 gallons of drainage daily from the factory. This drainage would all be discharged between the hours of 7 a.m. and 4 p.m., these being

approximately the times between which the volume figures were established. On the dates of observation the flow of the Waihi above the drainage influent averaged about 35 gallons per second, which for nine hours equals 1,134,000 gallons of water, into which 11,838 gallons of drainage flowed. The dilution was thus 1 in 100 during the nine hours of flow and 1 in 267 over the twenty-four hours. Below the drainage outlet, small tributary streams of reasonable quality gave still further dilution, but even at 3½ miles the total flow did not exceed 60 gallons per second—*i.e.*, a dilution of 1 in 452 in twenty-four hours. Such a comparatively low rate of dilution would explain the persistence of the contaminating effect for approximately 3 miles down-stream.

(b) THE TAWHITI STREAM

The Tawhiti is mainly swamp fed, it is comparatively slow flowing, and is populated by eels but not by trout. It receives drainage from two cheese factories of approximately 300 tons and 1,000 tons annual production situated within 4 miles of each other. It is generally regarded as being of reasonable quality below the second factory (where it was studied) and is used for the watering of stock. It was first surveyed on 29th and 30th December. On 29th December the early afternoon air temperature was 78° F., water temperature 74° F. The results are given in Table X. Point A was at the overflow from a drain maintained near the factory. Point B was the water from the same drain after passing through a mill race and water-wheel. A third overflow from the drain joined the stream above the point where sample 7 was taken. Visible effects of the drainage were evident over a much shorter distance than in the Waihi. The dissolved oxygen content became gradually lower up to the sampling point 7 at 1,000

TABLE X.—ANALYTICAL RESULTS FOR WATERS OF TAWHITI RIVER, 29TH AND 30TH DECEMBER

Sample No.	Distance from Factory Drainage Outflow.	Flow, Gallons/Seconds, 29th December	O_2 absorbed from Permanganate in Three Minutes at 100° C. (Parts per 100,000)		Dissolved O_2 per 10^6			
					Immediate.		After Five Days at 70° F.	
			29th December.	30th December.	29th December.	30th December.	29th December	30th December.
1	Above A ..	30	0·33	..	8·4	..	5·8	..
2	Above B ..	40	0·41	..	9·2	..	7·5	..
3	Ex-drain ..	..	..	0·41	..	8·7	..	3·7
4	Overflow of race	..	..	0·31	..	9·1	..	6·8
5	200 yards below..	85	0·38	0·65	6·7	5·4	2·0	Nil
6	600 yards below..	90	0·36	0·46	3·7	5·5	0·3	Nil
7	1,000 yards below	90	0·42	0·39	1·6	5·0	0·2	Nil
8	1 mile below ..	90	0·33	0·34	3·2	5·0	1·2	Nil
9	1½ miles below ..	93	0·55	0·41	4·1	6·3	0·6	5·1

yards, but had risen again in sample 8 at 1 mile from the outlet. The results for "oxygen absorbed" and for B.O.D. for the waters below the 1-mile sampling point show a certain amount of irregularity, probably due to the fact that the stream spreads out into a flat swampy area and does not flow between banks. There were also disturbances of sediment from the bottom of the stream on 29th December caused by fishing operations by local Maoris. These disturbances did not occur on 30th December.

A full analysis of five samples is given in Table XI :—

TABLE XI.—ANALYTICAL RESULTS FOR SAMPLES OF TAWHITI STREAM TAKEN ON 29TH AND 30TH DECEMBER

Analytical Determination	No 1: Ex-drain, 29th December	No. 2 200 Yards below Outlet, 29th December	No. 3. 1½ Miles below Outlet, 29th December.	No. 4. Above Outlet, 30th December	No 5: 1½ Miles below Outlet, 30th December.
Agar count per millilitre ..	14,500	285,000	11,600	10,300	9,200
Gelatine count per millilitre ..	39,600	820,000	33,000	28,400	26,000
Coliform test, limit	+ in $\frac{1}{10}$	+ in $\frac{1}{1000}$	+ in $\frac{1}{10}$	+ in $\frac{1}{10}$	+ in $\frac{1}{10}$
Total solids per 10^5 .. .	17·52	21·2	20·6	17·9	20·5
N_2 as free and saline NH_3 per 10^5	0·009	0·015	0·028	0·009	0·030
N_2 as albuminoid NH_3 per 10^5 ..	0·018	0·120	0·030	0·016	0·025
O_2 absorbed from $KMnO_4$ at 100 C. per 10^5	0·33	0·38	0·55	0·31	0·41
Dissolved O_2 per 10^6—					
(1) Immediate	8·4	6·7	4·1	9·1	6·3
(2) One day at 70° F. .	7·2	5·1	2·9	7·9	4·9
(3) Two days at 70° F. ..	6·5	3·2	0·1	7·2	3·8
(4) Five days at 70° F. ..	5·8	2·0	Nil	3·1	3·0

Nos. 1, 2, and 3 were taken at the points indicated in the early afternoon. Samples Nos. 4 and 5 were composite samples taken at half-hourly intervals at points above the factory and 1½ miles below the outfall respectively. Water No. 1 passes through a local swimming-pool and is apparently of acceptable quality. Water No. 2 is used freely for watering stock. Except for its lowered content of dissolved oxygen, it is comparable in every way with No. 1 sample and lower than it in bacterial count. Samples Nos. 4 and 5 were composites taken at half-hourly intervals at points above the factory and at 1½ miles below the outfall respectively. The results indicate that the Tawhiti had recovered in 1½ miles from the effects of the dairy effluent.

Composite samples were again taken on 3rd, 15th, and 17th January. The results are given in Table XII. The sample taken on 3rd January showed a deterioration in quality at 1½ miles for which no explanation can be offered, but the samples for the other two days support the view that in this stream the effect of the dairy effluent does not persist beyond 1½ miles. At 1 mile the effluent could not be detected by any visual examination, but its effect was evident from the destruction of dissolved oxygen over five days. Despite the effect of the swampy area above mentioned, the water at 1½ miles showed a recovery to the original bacterial quality of the Tawhiti. The water in the stream below the factory did not, however, reproduce at any point surveyed the highly oxygenated condition of the water above the drain.

By comparison with Table I, the analysis of the water of the Tawhiti at 1½ miles below the factory can be seen to be comparable with the analysis of the water of the Waihi above the point of entry of factory drainage and superior to it on a number of occasions.

TABLE XII.—ANALYTICAL RESULTS OF FURTHER COMPOSITE SAMPLES TAKEN FROM TAWHITI STREAM ON 3RD, 15TH, AND 17TH JANUARY

Test.	Sample 1: Ex Drain.			Sample No. 2 At 1 Mile below Outfall.			Sample No. 3: At 1¼ Miles below Outfall.		
	3rd January.	15th January.	17th January.	3rd January.	15th January.	17th January.	3rd January.	15th January.	17th January.
Agar count per millilitre	1,250	4,800	7,400	24,700	6,800	15,600	34,800	4,300	4,500
Gelatine count per millilitre	2,800	5,200	9,600	49,600	7,800	32,400	50,800	6,600	14,800
Coliform limit	− in $\frac{1}{100}$	+ in $\frac{1}{10}$	+ in $\frac{1}{10}$	+ in $\frac{1}{100}$	+ in $\frac{1}{100}$	+ in $\frac{1}{100}$	+ in $\frac{1}{10}$	+ in $\frac{1}{10}$	+ in $\frac{1}{10}$
Total solids per 10^5	18·70	18·8	19·0	19·6	19·3	19·8	22·7	19·6	23·2
NH_3, F. and S., per 10^5	0·025	0·017	0·015	0·028	0·009	0·009	0·020	0·010	0·011
NH_3, albuminoid, per 10^5	0·032	0·022	0·024	0·046	0·025	0·027	0·062	0·030	0·026
O_2 absorbed, per 10^5	0·26	0·13	0·19	0·35	0·21	0·19	0·59	0·26	6·23
Dissolved O_2 per 10^6—									
(1) Immediate	8·1	9·6	10·0	4·7	5·2	6·2	6·0	8·1	7·8
(2) One day at 70° F.	7·3	8·8	9·2	Nil	4·4	5·8	4·0	7·5	7·6
(3) Two days at 70° F.	6·8	7·3	7·3	Nil	3·7	5·5	3·9	6·7	5·9
(4) Five days at 70° F.	4·4	5·1	6·9	Nil	1·9	3·8	3·0	6·2	3·2

Relationship of Volume of Drainage to Flow of Tawhiti Stream

The factory discharging drainage into the Tawhiti was producing at the time of the survey about 9,160 lb. of cheese daily. Its effluent had already been measured as 0·26 gallons per pound of cheese(1), equivalent to a total of 2,382 gallons daily. The flow of the Tawhiti measured at a number of points below the factory was found to be 90 gallons per second, with practically no increase even at 1 mile below. The dilution, therefore, was 1 in 1,224 over nine hours, or 1 in 3,265 over twenty-four hours. At such a dilution the water could be expected to purify to a satisfactory quality within 1½ miles, even with the limited aeration given by the nature of the Tawhiti flow.

(c) THE KAPUNI RIVER

The Kapuni is a stream with very rapid and shallow flow. In places it is over 100 ft. wide, but it fills its stony bed only in parts. It is protected from stock in its upper reaches, where it is the source of the public water supply for the town of Hawera. After passing through farm lands it serves as a source of the public supply for the township of Manaia. Immediately afterwards it receives the drainage from a 450-ton cheese factory. It was sampled at the Manaia supply intake and below the outflow from the cheese factory. This locality is about 10 miles nearer Mount Egmont than the portion of the Tawhiti examined, and consequently the flow of water was more rapid.

The first examination was made on 5th January, 1941, during fine and warm weather, with air temperature 77° F. and water temperature 73° F. The factory drainage was being discharged into a side stream about 5 ft. wide and 1 ft. deep, close to one bank of the main river bed. About 50 yards below the outfall a second branch stream about 10 ft. wide and 9 in. deep joins the drainage flow, and at about another 50 yards lower the main stream joins in. At this point the river flow is about 20 ft. wide, has an average depth of 9 in., and a rate of about 3 ft. per second. Conditions here appeared very good. There was no discoloration or smell, and only occasionally could a fleck of solid dairy waste matter be seen passing. The stones of the bed were covered with green algæ, and there was a complete absence of the grey fungus so diagnostic of a contaminated water. The results in Table XIII indicate the quality of the water at various points along the stream.

TABLE XIII.—RESULTS OF EXAMINATION OF WATERS OF KAPUNI RIVER, 5TH JANUARY

Sample.	O_2 absorbed from Permanganate in Three Minutes at 100° C.	Dissolved O_2 per 10^6.	
		Immediate.	After Five Days at 70° F.
(1) River above intake for Manaia public supply	0·05	9·0	8·0
(2) Side stream receiving drainage above outfall	0·09	8·4	7·4
(3) Side stream, 50 yards below outfall	0·12	8·4	6·0
(4) Tributary side stream B ..	0·05	8·7	7·9
(5) Main stream before joining flow containing drainage	0·04	9·3	8·0
(6) Main stream after junction ..	0·05	8·8	7·4

From these figures it appeared that the effect of the drainage upon the quality of the Kapuni was marked only in the small side stream. This is confirmed by the results of full analyses shown in Table XIV.

TABLE XIV.—FULL ANALYSES OF WATERS OF KAPUNI RIVER, TAKEN AT 3 P.M. (5TH JANUARY) DURING THE HEIGHT OF FLOW OF AFTERNOON FACTORY DRAINAGE

Test	Sample 1: River above Manaia Public Supply Intake.	Sample 2: Full River, about 100 Yards below Sewage Outfall.
Agar count per millilitre	11,400	17,200
Gelatine count per millilitre	72,400	66,400
Coliform test (limit)	+ in $\frac{1}{10}$	+ in $\frac{1}{10}$
Total solids per 10^5	11·06	10·98
N_2 as free and saline NH_3 per 10^5	0·0100	0·0180
N_2 as albuminoid NH_3 per 10^5	0·0132	0·0171
O_2 absorbed from permanganate in three minutes at 100° C. per 10^5	0·05	0·05
Dissolved oxygen per 10^6—		
(1) Immediate	9·0	8·8
(2) After one day	8·2	7·6
(3) After two days	8·1	7·2
(4) After five days	7·1	5·7

Bacterial counts were of the same order above and below: there were no significant changes in content of total solids or of "organic matter" as indicated by the permanganate test, there was a moderate increase in the ammonia figures, and also a perceptible influence upon the absorption of dissolved oxygen. Although the sample analysed was a single sample taken at the time of the maximum afternoon flow, the results show that the Kapuni after receiving the dairy drainage was better in quality than the Waihi and Tawhiti before receiving the factory drainage.

The Kapuni was investigated at length on 8th January during continued fine weather. Samples were taken at half-hourly intervals all day at the first point of complete mixing in the full stream. The lowest value found for dissolved-oxygen content was 9·10 p.p.m. at 3.30 p.m., while the highest value above the outfall was 10·3 p.p.m. Farther down-stream immediate increases in dissolved-oxygen content were found, due to the presence of rapids not far below (compare the decreases in dissolved-oxygen content with distance in both the Waihi and the Tawhiti). Thus, 200 yards farther downstream, values of 10·6 p.p.m. for dissolved oxygen persisted all day, while another 100 yards farther the value stood constant at 11·0 p.p.m. Evidently dairy waste matter was being rapidly oxidized within 200 yards of the first point of complete mixing with the main stream.

Two composite samples were collected at half-hourly intervals between 9.30 a.m. and 3.30 p.m. (see Table XV).

TABLE XV.—DETAILED ANALYSIS FOR COMPOSITE SAMPLES OF THE KAPUNI RIVER: SAMPLES TAKEN 9.30 A.M. TO 3.30 P.M.

Test.	Sample 1: Kapuni River above Drainage, 8th January.	Sample 2: Kapuni River 100 Yards below Drainage Outfall.
Agar count per millilitre	3,240	13,250
Gelatine count per millilitre	Liquefied and uncountable	Liquefied and uncountable
Coliform test (limit)	+ in 1	+ in $\frac{1}{100}$
Total solids per 10^5	11·00	10·98
Nitrogen as free and saline ammonia per 10^5 ..	0·0063	0·0070
Nitrogen as albuminoid ammonia per 10^5	0·0095	0·0154
Oxygen absorbed from permanganate at 100° C. per 10^5	0·04	0·07
Dissolved oxygen, p.p.m.—		
(1) Immediate	10·3	9·9
(2) One day at 70° F.	8·1	6·7
(3) Two days	7·1	5·9
(4) Five days	4·9	4·3

This test showed a definite effect of the drainage, but nevertheless indicated a water of reasonable quality, quite fit for cattle drinking, and stable on keeping. Possibly the high gelatine count and abnormal coliform titre of the original water prevented the stream from making the superior recovery noted on 5th January, but evidently the distance from the outfall was too short in which to expect complete recovery.

On 20th January, therefore, composite samples were again taken from the Kapuni at the same two places as before, and also at a point about 300 yards below the second (see Table XVI). The weather was cool and dull and the river was slightly discoloured and rising after heavy rain on the previous night. Subsequent to the last sampling, between 10th to 12th January heavy rain had caused floods, which no doubt had the effect of cleaning out the bed of the stream.

TABLE XVI.—FURTHER DETAILED ANALYSES OF WATERS FROM KAPUNI STREAM, 20TH JANUARY

Test.	Sample 1: Above Drainage.	Sample 2. 100 Yards below Outfall.	Sample 3: 400 Yards below Outfall.
Agar count per millilitre	5,800	18,500	6,100
Gelatine count per millilitre ..	19,200	65,000	24,200
Coliform test (limit)	+ in $\frac{1}{10}$	+ in $\frac{1}{100}$	+ in $\frac{1}{10}$
Total solids per 10^5	11·48	11·54	11·40
Nitrogen as free and saline ammonia per 10^5	0·0128	0·0184	0·0140
Nitrogen as albuminoid ammonia per 10^5	0·0098	0·0196	0·0108
Oxygen absorbed from permanganate at 100° C. per 10^5	0·06	0·09	0·05
Dissolved oxygen per 10^6—			
(1) Immediate	10·4	10·0	10·5
(2) One day at 70° F.	9·3	6·8	9·6
(3) Two days	8·4	4·4	8·8
(4) Five days	7·7	1·2	8·3

The tests showed that at 100 yards below the outfall recovery was definitely not complete, though the quality of the water was reasonable, but that 400 yards below the outfall the quality of the Kapuni had returned to its original.

Another set of samples was taken on 8th February in overcast weather. There had been rain on Mount Egmont and the river was much higher than on previous days. It was also discoloured and running more rapidly.

On this occasion sample 3 was collected about 500 yards below the outfall and below a shallow where some cattle came once during the day to drink. Even with this disturbance the analysis was not badly affected and showed a completely recovered water at the greater distance.

Relationship of Volume of Drainage to Volume of Flow of Kapuni River

The Kapuni is a fast-flowing stream, fed directly from the snows of Mount Egmont, and possessing a marked fall at the point where sampled. It is therefore very variable in flow, being responsive to weather changes and local rain on Mount Egmont. On 5th January, measurements gave a flow of about 410 gallons per second; on 8th January, 390 gallons; on 20th January, 470 gallons; and 8th February, in two different places, 730 gallons and 750 gallons per second.

The factory whose drainage ran into the Kapuni had been studied previously and gave 0·9 gallons drainage per pound of cheese, with an average output of 4,047 lb. of cheese daily for the month of January. Thus approximately 3,640 gallons of drainage daily were being run into the Kapuni during the usual hours of 7 a.m. to 4 p.m. Taking the flow of the Kapuni as about 400 gallons per second, rising to 740 gallons per second, the dilutions lie between 1 in 3,560 and 1 in 6,587 for the nine-hour period, or 1 in 9,494 and 1 in 17,564 for the twenty-four-hour period, according to the state of the river.

Since at the lowest dilution observed, on 8th January, the river had satisfactorily recovered within 400 yards, the dilution of 1 in 3,560 can be cited as one which enables a well-oxygenated river to purify to its original quality within 400 yards.

(*d*) THE KAUPOKONUI RIVER

The Kaupokonui, South Taranaki's largest river, rises on Mount Egmont from a snow-filled gorge within a short distance of the source of the Kapuni. When only about 6 miles clear of the mountain reserve it receives the drainage from two cheese factories (total output, approximately 800 tons) within about 300 yards of each other.

The first survey was made on 16th January in fine weather, with air temperature 68° F. and water temperature 63° F. The river was very low at the time. The samples were taken at a time when there was visible discoloration from the mid-afternoon flow of drainage. The results of a preliminary examination of five samples are given in Table XVII, and a full analysis of three of the samples in Table XVIII. Samples 2 and 3 are shown

TABLE XVII.—PRELIMINARY EXAMINATION OF WATER OF KAUPOKONUI RIVER, 16TH JANUARY

Position from which Sample taken.	Dissolved Oxygen.	
	Immediate.	After Five Days at 70° F.
(1) Above both factories	10·6	8·2
(2) 50 yards below outfall of No. 1 factory	11·0	7·0
(3) 200 yards below outfall of No. 1 factory ..	11·1	7·8
(4) 50 yards below outfall of No. 2 factory	11·3	5·6
(5) 200 yards below outfall of No. 2 factory ..	11·3	6·1

TABLE XVIII.—FULL ANALYSES OF SAMPLES 1, 2, AND 3

Test.	Sample 1: Kaupokonui River above Factory A.	Sample 2: 50 Yards below Factory A.	Sample 3: 200 Yards below Factory B.
Agar count per millilitre	1,300	4,500	3,900
Gelatine count per millilitre ..	2,300	3,900	4,000
Coliform test (limit)	— in 1 ml.	+ in $\frac{1}{100}$	+ in $\frac{1}{10}$
Total solids per 10^5	8·90	8·88	8·94
Nitrogen as free and saline ammonia per 10^5	0·0055	0·0053	0·0052
Nitrogen as albuminoid ammonia per 10^5	0·0111	0·0112	0·0117
Oxygen absorbed from permanganate at 100° C. per 10^5	0·01	0·01	0·01
Dissolved oxygen, p.p.m.—			
(1) Immediate	10·6	11·0	11·3
(2) One day at 70° F.	9·7	9·8	9·6
(3) Two days	9·2	8·6	8·0
(4) Five days	8·2	7·0	6·1

to be slightly inferior in quality to sample 1, but they are still waters of reasonable chemical purity superior to most shallow-well waters and streams in stocked areas. Satisfactory recovery appears thus to have taken place within 50 yards of factory A and within 200 yards of factory B. Further investigations on 27th January and 1st February confirmed this (see Table XIX), and showed that at a point 200 yards below the place where sample 3 (Table XIX) was taken the effect of the drainage had practically disappeared. Light rain fell at intervals during the time of sampling on 27th January, and some slight deterioration of the quality of samples 2 and 3 could be expected on account of the access of surface drainage from a road.

TABLE XIX.—ANALYSIS OF COMPOSITE SAMPLINGS OF KAUPOKONUI RIVER: AVERAGE RESULTS FOR 27TH JANUARY AND 1ST FEBRUARY

Test.	Sample 1 Above Factory A.	Sample 2 200 Yards below Factory B	Sample 3: 400 Yards below Factory B.
Agar count per millilitre	1,850	4,280	2,500
Gelatine count per millilitre ..	79,600	199,200	106,000
Coliform test (limit)	+ in 1	+ in $\frac{1}{10}$	+ in $\frac{1}{10}$
Total solids per 10^5	8·65	8·64	8·60
Nitrogen as free and saline ammonia per 10^5	0·0058	0·0114	0·0066
Nitrogen as albuminoid ammonia per 10^5	0·0075	0·0089	0·0083
Oxygen absorbed from permanganate at 100° C. per 10^5	0·01	0·01	0·01
Dissolved oxygen, p.p.m.—			
(1) Immediate	9·7	9·4	9·4
(2) One day at 70° F.	8·9	7·4	8·4
(3) Two days	8·6	6·7	7·4
(4) Five days	8·0	6·0	6·9

The only time when the quality of the Kaupokonui seemed to be clearly lower at 400 yards below factory B than at above A occurred on 23rd February, when the river was at its record low level. Stones never before observed were now uncovered, and these were found, at the 200 yards point, coated with a brownish slime containing small white particles underneath. There was, however, no active decomposition going on, and no putrid smell associated

with the deposit. In a small backwater freely lined by this deposit, in which mosquito larvæ were breeding, the dissolved oxygen content was 9·1 p.p.m., a figure high enough to prove absence of bacterial putrefaction. In any case, there was plenty of green algæ about, and trout of various sizes were observed. This coating on the stones was traced all the way to the factory, but did not persist much beyond the 200 yards mark, and could not be found at the 400 yards mark. Three composite samples were analysed in full at this time of maximum apparent effect of the drainage (Table XX).

TABLE XX.—COMPOSITE SAMPLES FROM KAUPOKONUI RIVER AT RECORD LOW LEVEL, 23RD FEBRUARY

Test.	Sample 1: Above Factory A.	Sample 2: 200 Yards below Factory B.	Sample 3: 400 Yards below Factory B.
Agar count per millilitre	1,920	4,560	2,380
Gelatine count per millilitre	2,260	5,560	5,320
Coliform test (limit)	+ in 1	+ in $\frac{1}{100}$	+ in $\frac{1}{10}$
Total solids per 10^5	10·95	11·16	11·06
Nitrogen as free and saline ammonia per 10^5	0·0076	0·0089	0·0080
Nitrogen as albuminoid ammonia per 10^5	0·0112	0·0165	0·0126
Oxygen absorbed from permanganate at 100° C. per 10^5	0·01	0·10	0·08
Dissolved oxygen, p.p.m.—			
(1) Immediate	9·0	9·4	9·4
(2) One day at 70° F.	8·6	7·0	7·8
(3) Two days at 70° F.	8·4	6·1	5·6
(4) Five days at 70° F.	7·5	3·1	4·3

Samples 2 and 3 were definitely inferior to sample 1, but were not heavily contaminated. Even the bacterial populations were not excessive, notwithstanding the fact that visible discoloration from the dairy wastes was evident at intervals during the day. The improvement in the 200 yards of river between sampling points 2 and 3 was very marked, indicating that in only a moderate extra distance the process would be complete, despite the condition of the river at the time of the survey—viz., minimum dilution for the drainage and slower flow of water.

Relationship of Volume of Drainage to Volume of Flow of Kaupokonui River

Like the Kapuni, the Kaupokonui has a steep fall, and is quickly affected by weather fluctuations on Mount Egmont, many of which do not affect the general weather of the province. In its higher reaches, therefore, it rises or falls in volume almost daily. Measurements of its flow gave 625 gallons per second on 16th January, 850 gallons on 27th January, and 640 gallons on 1st February. During that month the normal manufacture of factory A was approximately 3,500 lb. of cheese and 800 lb. butter, while factory B produced 4,080 lb. cheese daily. Allowing 0·9 gallons of drainage per pound of cheese and 1·3 gallons per pound of butter, as already established for small pasteurizing factories, the total daily drainage was approximately 7,862 gallons from both factories. This volume entering the river (7 a.m. to 4 p.m.), flowing at 625 gallons per second during nine hours (7 a.m. to 4 p.m.), is diluted 1 in 2,576, or 1 in 6,869 for the twenty-four-hour period. For a flow of 850 gallons per second, the dilution figure would be 1 in 3,502 for nine hours and 1 in 9,342, for twenty-four hours.

These dilutions are thus not so high as those for the Kapuni River, notwithstanding the fact that recovery of the Kaupokonui appeared more rapid. Comparison, however, is hardly logical. The Kapuni received its

drainage at one point only, and was found to be not seriously affected 200 yards down-stream, and completely recovered 400 yards below the outfall. The Kaupokonui receives drainage from factory A and flows for about 300 yards before reaching factory B, receiving meanwhile the thorough aeration of passage through a hydro-electric power unit. As shown by Table XVIII, there is a swift recovery from the effect of drainage from factory A. The effect of factory A can therefore be disregarded, in so far as it could influence conditions 200 yards to 400 yards below factory B. If this view-point is accepted, the dilutions below factory B would be 1 in 5,515 for nine hours and 1 in 14,707 for twenty-four hours, rising to 1 in 7,500 for nine hours and 1 in 20,000 for twenty-four hours. Such figures then do not conflict with the findings for the Kapuni that a dilution of 1 in 3,560 for a nine-hour period is sufficient to enable a well-oxygenated river to purify to its original quality within 400 yards.

During the record low level in the Kaupokonui on 23rd February the recovery at 400 yards below factory B was still incomplete. On this day the flow was considerably diminished, not so much by a proportional decrease in the depth of the stream as by a great diminution in its speed. Measurements at the point of sampling showed not more than 140 gallons per second going past. Even on the most favourable basis of considering factory B alone, the dilution was only 1 in 1,235 for nine hours or 1 in 3,293 for twenty-four hours. Failure to purify within 400 yards was thus a confirmation of the conclusion already put forward. By comparison with the dilution normally obtained in the Tawhiti, one might expect that during the low, slow flow of the Kaupokonui the dairy drainage might have been detected by analysis at almost 1½ miles below factory B. The superior oxygenation of the Kaupokonui, however, would certainly shorten this distance.

GENERAL CONCLUSIONS

The effect of dairy factory drainage on a natural stream is shown to be dependent on the degree of dilution afforded, on the degree of oxygenation of the water as it receives the drainage, and on the amount of oxygenation the water receives after the inflow of drainage. With a slow-flowing stream of small volume such as the Waihi the effect of the drainage on the water may persist for 3 miles, but with a rapid-flowing stream putrefaction takes place within a very short distance, and the degree of de-oxygenation never falls to the danger point for trout. In general, for a well oxygenated stream a dilution of 1 in 3,500 over a nine-hour period of discharge is adequate for maintenance of reasonable quality in the water.

It was found that the classical chemical determinations were not particularly diagnostic except where the original water was also examined and the results could be compared. Bacteriological results were invariably more sensitive. Of the chemical tests, the absorption of dissolved oxygen in five days (five day biochemical oxygen demand) was the best evidence of the presence of dairy effluent, even in small concentration.

ACKNOWLEDGMENTS

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REFERENCE

(1) VEALE, P. O. (1941): *N.Z. J. Sci. & Tech.* (1942), **23**, 166A.

FLUORINE IN NEW ZEALAND SOILS

By G. D. GEMMELL, Soil Survey Division, Department of Scientific and Industrial Research

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Summary

Total fluorine in some New Zealand soils has been determined by a colorimetric method based on the thorium-nitrate - alizarin-sulphonate procedure proposed by Willard and Winter (1933). The figures range from 68 p.p.m., to 540 p.p.m., being of the same order as those reported by workers overseas.

INTRODUCTION

As there is an apparent relationship between low fluorine intake and diminished resistance to dental caries, the Nutrition Committee of the New Zealand Medical Research Council asked this Division to undertake a fluorine survey of the main New Zealand soil types. While it was realized that a knowledge of the available fluorine in soils would be more useful than total fluorine from the nutritional viewpoint, no record of work in this direction was found in the literature, and therefore, in order to compare figures for the fluorine content of New Zealand soils with results obtained overseas, it was decided to determine total fluorine content before proceeding further in the investigation. Information on the fluorine content of soils of other countries is very meagre. Steinkoenig (1919) examined eight soils, while MacIntire and Hammond of Tennessee (1939) and McHargue and Hodgkiss of Kentucky (1939) have reported the fluorine content of a few soils.

DETERMINATION OF FLUORINE IN SOILS

Fahey (1939) has observed that twenty analytical techniques—gravimetric, volumetric, colorimetric, and nephelometric—for the quantitative determination of fluorine were proposed between 1816, when the original method by Berzelius appeared, and 1936, when the literature was reviewed by Stevens (1936). The lead chlorofluoride method developed by Hoffman and Lundell (1929) is widely used in the analysis of materials of relatively high fluorine content. However, it was not until the thorium nitrate volumetric method was proposed by Willard and Winter (1933) that a dependable technique for the determination of minute quantities of fluorine was developed.

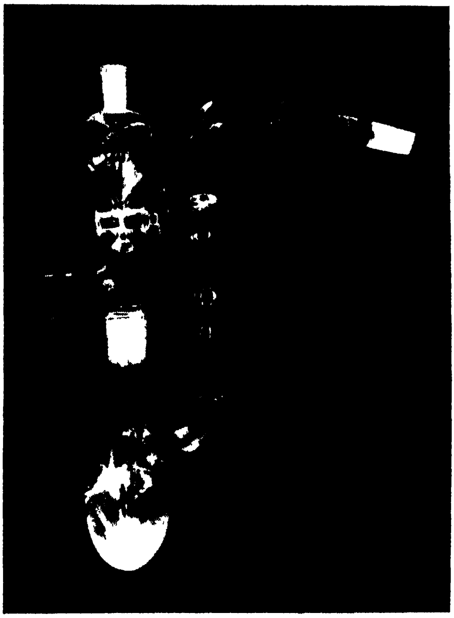
In this method the solute fluoride is titrated to thorium fluoride, and upon further addition of the thorium nitrate a pink " lake " is formed by reaction with the alizarin sulphonate indicator. For the present work a colorimetric technique involving comparison with standard fluoride solutions was considered preferable to direct titration.

Prerequisites for the determination of the fluorine content of soils are (*a*) fixation of the element and its conversion to compounds that may readily be dissolved by digestion, and (*b*) separation of the element from substances which interfere in the determination. Particular stress is laid upon preparation of analytical samples, as considerable difficulty has been encountered in obtaining representative samples for analyses.

From the findings of other workers and the results of further studies the procedure adopted is as follows :—

Apparatus

Pyrex glass and standard Quickfit and Quartz joints are used for the distillation unit (Fig. 1). The distillation flask should be treated with hot 10 per cent. sodium hydroxide before every determination, in order to remove any accumulations of silica which retard the volatilization of fluorine. For colorimetric comparison, Nessler tubes with fused-on plane bottoms are most satisfactory. To minimize local superheating in the flask during the steam distillation, the use of molten Wood's metal instead of a direct flame is recommended. A stirring rod bent to a circle at the lower end to be parallel to the bottom of the Nessler tube is suitable for mixing the contents of the tube.



[*Photo by A. J. Metson.*

FIG. 1.—Distillation unit for determination of fluorine in soil.

Reagents

Calcium Hydroxide Suspension (Fixation Agency).—To prepare a lime suspension with a negligible content of fluorides, the following technique, based on that prescribed by Clifford (1941), is recommended: to 56 g. of calcium oxide in a 1-litre Pyrex beaker add approximately 20 ml. of distilled water slowly and then add 250 ml. of 60 per cent. perchloric acid slowly with stirring. Boil, while passing air or steam to prevent bumping, until copious fumes are evolved. Add 300 ml. of distilled water and boil as before. Repeat four times. Dilute and filter through a sintered glass filter. Pour the filtrate slowly into 1 litre of 10 per cent. sodium hydroxide solution in a Pyrex beaker and allow the calcium hydroxide precipitate to settle. Decant the supernatant liquid, filter through sintered glass, and wash

the precipitate thoroughly with water. From the precipitate make up a 10 per cent. suspension of calcium oxide in distilled water. Preserve in a paraffin-lined glass container.

Perchloric Acid.—60 per cent.

Sodium Alizarin Sulphonate Indicator.—0·05 per cent. aqueous solution.

Thorium Nitrate.—0·002N aqueous solution.

Buffer Solution (as recommended by Hoskins and Ferris (1936)).—Sodium hydroxide - monochloroacetic acid solution at a ratio of 0·5 and total concentration of 0·02M in 48 per cent. ethanol solution.

Standard Fluorine Solution.—Using A.R. sodium fluoride, prepare a stock solution of 0·020 per cent. fluorine concentration and preserve in a stoppered paraffin-lined container. For use, dilute to 1 p.p.m. It has been found that a solution of concentration 1 p.p.m. will keep in a stoppered Pyrex container for at least two months without appreciable change in concentration.

Phenolphthalein Solution.—0·5 per cent in 60 per cent. ethanol.

p-Nitro-phenol.—0·5 per cent. in 60 per cent. ethanol.

Procedure

In an agate mortar grind 10 g. of a thoroughly mixed 2-mm.-sieved sample of an air-dried soil to pass a 300-mesh sieve and preserve in a stoppered container. Weigh a 2 g. charge of the 300-mesh sample into a nickel crucible and impregnate with sufficient calcium hydroxide suspension to supply about 1 g. of calcium oxide. Evaporate the mixture to dryness on an electric hot plate and incinerate for ten minutes at 500° c. in an electric furnace and then ignite for an hour at 900° c. Cool, transfer the ignited mixture to the distillation flask, and rinse the crucible with a small quantity of perchloric acid. Wash down the walls of the flask dropwise with distilled water, add three drops of phenolphthalein, introduce a spatula-tip portion of A.R. silver sulphate, and add a few glass beads. Insert the dropping funnel into the flask and connect with the steam supply without allowing the entry of any steam. Connect a condenser to the flask and run in from the funnel sufficient 60 per cent. perchloric acid to neutralize and 15 ml. additional. Immerse the bottom of the flask in a bath of molten Wood's metal which is kept at a temperature of about 200° c. The surface of the molten metal should be well below the surface level of the contents of the flask. When the temperature of the solution-suspension in the flask rises to 135° c., pass in a current of steam sufficient to keep the temperature between 135° c. and 140° c. Maintain this temperature by regulating the steam supply and collect 200–250 ml. of distillate in a 250 ml. volumetric flask and make up to volume. Continue to collect the distillate in approximately the same portions until all the fluorine is expelled. As the fluorine content of the portions collected diminishes, it will be necessary to concentrate the solutions for the determination. To do this, make the solution just alkaline to p-nitro-phenol indicator with N/100 sodium hydroxide and evaporate on an electric hot plate in a covered platinum or Pyrex vessel to the required volume. The acidity of the distillate should not exceed 0·0005N.

The fluorine content of each distillate portion is determined as follows: transfer an aliquot containing about 10–20 μg. of fluorine to a Nessler tube and make up with water to a fixed volume, say, 20 ml. If concentration has been necessary, neutralize carefully with N/100 hydrochloric acid to

destroy the colour of the p-nitro-phenol. In either case add 0·4 ml. of the alizarin sulphate indicator and adjust the pH with N/100 sodium hydroxide or N/100 hydrochloric acid to the neutral colour of the indicator. Add 20 ml. of buffer solution. Add carefully, with stirring, sufficient of the thorium nitrate solution to give a faint pink colour suitable for colorimetric matching and make up to 50 ml. with 48 per cent. alcohol solution. With another Nessler tube, repeat the procedure, but omit the initial addition of the aliquot, then add carefully with stirring sufficient standard 1 p.p.m. fluorine solution to give the same depth of colour when made up to 50 ml. as that obtained with the aliquot. In this way the approximate fluorine content of the aliquot is determined. However, if a series of determinations is to be done it is advisable to compile a graph giving the approximate interrelation of fluorine content and thorium nitrate required, and the above step in each determination is then unnecessary. Make up four tubes for comparison, one with an aliquot of the distillate and the others with standard solution in quantities differing by 1 μg. so that the middle of the range corresponds with the known approximate value. Make all the tubes up to the fixed volume with water before adding the indicator and the buffer solution, &c. The estimation is sensitive to 0·5 ml. of standard fluorine solution and its accuracy is thus 2·5 per cent. for 20 μg. of fluorine and 10 per cent. for 5 μg. of fluorine.

TABLE I. FLUORINE CONTENT OF SOME NEW ZEALAND SOILS

Laboratory Number.	Type	Classification.	Fluorine Content. (p.p.m.).
1460A ..	Motatau clay	Rendzina	540
1364A ..	Te Horo peat	Mellow peat	384
1377A ..	Maunu loam	Immature red loam . ..	315
899A ..	Mohaka sandy loam ..	Immature podzolic soil from pumice	291
2489A ..	Taitapu silt loam ..	Recent soil from alluvium ..	250
2143A ..	Alexandra sandy loam ..	High-land tussock soil	243
2147 ..	Manawatu clay loam ..	Recent soil from alluvium ..	226
1294A ..	Ngauruhoe gravelly sandy silt	Recent soil from volcanic ash ..	220
826 ..	Mount Adams clay loam..	Semi-mature podzolic soil ..	204
2745 ..	Seafield silt loam ..	Low-land tussock soil	191
1323 ..	Hauraki Plains Clay ..	Meadow soil (from estuarine clay)	165
1272A ..	Paengaroa medium sand..	Immature podzolic soil from pumice	156
1526 ..	Clydevale heavy silt loam	Low-land tussock soil	148
894A ..	Mairoa silt loam ..	Semi-mature yellow-brown loam	145
1577 ..	Fairfax silt loam ..	Tussock soil (transition to yellow earth)	114
1963A ..	Horotiu sandy loam ..	Immature yellow-brown loam ..	109
1157A ..	Kaharoa sand	Sub-mature podzolic soil from pumice	108
1499A ..	Waiwera clay	Immature yellow earth	107
934A ..	Morrinsville clay loam ..	Immature brown granular clay ..	107
1865A ..	Waipa clay loam ..	Recent soil, meadow phase ..	94
1223A ..	Tarawera gravel ..	Recent soil from volcanic ash ..	85
1871A ..	Mangakahia clay loam ..	Recent soil, meadow phase ..	78
867 ..	Pinaki coarse sand ..	Young podzolic soil from blown sand	68

DISCUSSION OF RESULTS

These results are of the same order as those reported by workers overseas. Steinkoenig (1919), using a modification of Merwin's method, found an average fluorine content of 300 p.p.m. in eight soils with a range from a

trace to 1,500 p.p.m. MacIntire and Hammond (1939), using essentially the same method as in the present work, reported fluorine contents of 205, 185, 315, 154, 138, and 488 p.p.m. in soils used for pot experiments. In the present work, difficulty was experienced in getting uniformity in duplicate determinations, it being not uncommon to get variations of 20 per cent. and more. Also, it is emphasized that results are for single samples only, and are not to be taken as being representative of particular soil types. However, the above figures serve to give an indication of the general level of total fluorine in New Zealand soils.

The mechanism by which fluorine limits dental caries is still under investigation by workers overseas, and until it is established that fluorine in soils is of significance it is proposed to go no further with this investigation.

ACKNOWLEDGMENT

The author wishes to acknowledge the generous assistance of W. H. MacIntire, Head of the Department of Chemistry of the University of Tennessee Agriculture Experiment Station.

REFERENCES

CLIFFORD, P. A. (1941): *J. Assoc. Off. Agr. Chem.*, *24*, 360–1.

FAHEY, J. J. (1939): *Ind. Eng. Chem., Anal. Ed.*, *11*, 362–3.

HOFFMAN, J. I., and LUNDELL, G. E. F. (1929): *U.S. Dept. Com. Bur. Standards Res. Paper 110.*

HOSKINS, W. M., and FERRIS, C. A. (1936): *Ind. Eng. Chem., Anal. Ed.*, *8*, 6–9.

MACINTIRE, W. H., and HAMMOND, J. W. (1939): *J. Assoc. Off. Agr. Chem.*, *22*, 231–6.

MCHARGUE, J. S., and HODGKISS, W. S. (1939): *J. Assoc. Off. Agr. Chem.*, *22*, 249–52.

STEINKOENIG, L. A. (1919): *Ind. Eng. Chem.*, *11*, 463–5.

STEVENS, R. E. (1936): *Ind. Eng. Chem., Anal. Ed.*, *8*, 248–52.

WILLARD, H. H., and WINTER, O. B. (1933): *Ind. Eng. Chem.*, *5*, 7–10.

CHEMICAL ANALYSIS OF CLAYS

PART I.—DETERMINATION OF R_2O_3 AND ALKALIES

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[*Received for publication, 1st November, 1945*]

Summary

(*a*) In a previous paper(1) the writer described a simplified method of determining alkalies in silicates, in the course of which total R_2O_3 remains as a residue after extraction of alkali sulphates with water. The present paper deals with further analysis of this by-product to determine the iron, titanium, and aluminium of the sample. This gives, for many clays, all the additional chemical information required for works practice.

(*b*) When the clay contains appreciable magnesium, this remains mostly in the R_2O_3 residue, and must be extracted separately by means other than water to obtain the true weight of R_2O_3.

INTRODUCTION

IN the *Analyst* of August, 1944(1), the author described a simplified method of determining alkalies in silicates as follows: decompose a 1 g sample with 4 ml. of 1 : 1 H_2SO_4 and 8·10 ml. of HF. Evaporate to complete dryness, cool, add 2 ml. of 1 : 1 H_2SO_4, and fume again to dryness. Heat carefully to 900° C. to decompose sulphates of iron, aluminium, and titanium. Leach with water, and transfer the R_2O_3 residue to a 7 cm. paper.

For a second extraction ignite the paper, fume the residue with 4 ml. 1 : 1 H_2SO_4 to dryness, heat, and leach with hot water through a 7 cm. paper until the combined extracts measure 100 ml. In aliquot portions determine sodium as uranyl-acetate and potassium as cobaltinitrite.

It was further stated that the R_2O_3 residue from extraction of alkali sulphates could be employed with many clays for accurate determinations of iron, titanium, and aluminium, and that these determinations, in conjunction with alkali determinations and loss on ignition, gave in such cases all the chemical information required in works practice.

It was conceded, however, that where the clay contained appreciable magnesium the R_2O_3 residue would be contaminated with magnesia through almost complete thermal decomposition of magnesium sulphate. It would not, however, retain calcium sulphate, unless lime were present in the sample in more than a moderate amount (say 1·2 per cent.).

The usual procedure in analysing total R_2O_3 is to ignite and weigh, fuse with pyrosulphate, bring into solution with sulphuric acid, reduce the iron with H_2S(2, p. 304), titrate with permanganate for ferric oxide, and then estimate titania colorimetrically with H_2O_2.

The more convenient Zimmermann-Reinhardt reduction of iron with stannous chloride, as modified by Knop(3), is open to the objection that titania cannot be determined later. We might, indeed, follow the technique of Dittler(4, pp. 22–3) and determine iron after titanium, or another method, even more promising, wherein iron is reduced before solution—namely, to metal by reduction in hydrogen(5). But both these procedures are complicated in the case of clays by the highly aluminous nature of the R_2O_3 residue.

Probably the simplest means of determining both iron and titanium is that used by McNamara(6, p. 355)—reduction of iron in sulphuric acid solution by the Jones Reductor*(7, p. 346; 2, p. 101.).

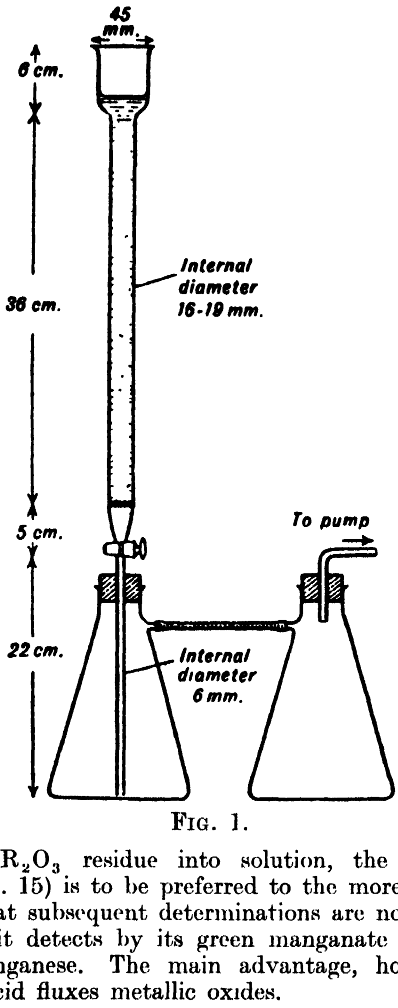

FIG. 1.

To bring the R_2O_3 residue into solution, the use of soda-borax flux(8, p. 19; 4, p. 15) is to be preferred to the more usual pyrosulphate fusion, provided that subsequent determinations are not gravimetric. One advantage is that it detects by its green manganate colour the presence of appreciable manganese. The main advantage, however, is the ease with which boric acid fluxes metallic oxides.

(A) ANALYSIS OF R_2O_3 RESIDUES FREE OF MgO

At the end of the " second extraction " for alkalies, transfer the powdery leached oxides completely to paper, and while the combined extract is evaporating transfer paper and contents to a fairly large weighed platinum

* A suitable form, with approximate dimensions, is shown in Fig. 1. A perforated plate (or, better, a coarse sintered-glass disc, porosity 0, capable of being fused into the walls of the glass tube), covered with glass wool, supports the zinc column. The " cup " is of approximately 50 ml. capacity, and the flask 500 ml. or 750 ml. For the column, about 300 g. of A.R. pure 20–30 mesh zinc are amalgamated by covering in a basin with 2 per cent. solution of mercuric chloride containing a little sulphuric acid, and stirring for five to ten minutes so that the zinc acquires a bright silvery lustre. The zinc is then washed several times with water. The column reaches the bottom of the cup, and must be kept filled with water to prevent the formation of basic salts by atmospheric oxidation. During use, also, the liquid in the cup should always be replenished before its level falls to the top of the zinc column.

crucible, burn off the paper, and ignite strongly on a good blast, to obtain combined weight of Fe_2O_3, Al_2O_3, and TiO_2. Prepare the oxides for solution in acid by fusion with pyrosulphate or with soda-borax mixture.

Pyrosulphate Fusion.—Add to the ignited R_2O_3 in the crucible ten times its weight of "fused potassium bisulphate." Heat on a triangle over a Bunsen flame, commencing with the flame fairly low, and keeping the melt gently fuming for some time, while occasionally swirling the crucible. Raise the temperature gradually at last to complete the solution to a clear reddish melt. Cool the crucible while swirling. Place it in a small covered beaker with 50 ml. of hot water containing 10 ml. of 1 : 1 H_2SO_4, and put this on the water-bath until solution appears complete. To get a perfectly clear solution, filter through a 7–8 cm. medium-open paper containing a little paper-pulp into a 150 ml. beaker marked at 100 ml., and wash. (If turbidity before filtering seemed possibly due to unfluxed titanja or alumina, return the paper to the crucible, burn off, and re-fuse the residue with a little pyrosulphate, dissolve in the crucible in a little hot 5 per cent. H_2SO_4, and pass through a small filter into the beaker). Wash up to 100 ml. mark on the beaker, and cool.

Soda Borax Fusion (Alternative to Pyrosulphate).—Make up this fusion-mixture by mixing intimately five parts of soda-ash with one part of "fused and powdered" borax (completely dehydrated). To the platinum crucible containing the ignited and weighed R_2O_3 residue add ten times that weight of soda-borax, and with a small pestle gently grind the powdery residue and the flux together. Heat on a triangle over a full Bunsen flame to fusion, but not necessarily to so clear a melt as with pyrosulphate. Cool the crucible well(8, p. 19, warning footnote *re* "Leidenfrostsche" phenomenon), place in a small covered beaker, and add gradually about 50 ml. of cold water containing 10 ml. of 1 : 1 H_2SO_4 plus 1 ml. of acid for each gram of soda-borax used. Leave until effervescence slackens, then dissolve on the water-bath. If the solution is in the least turbid (as from such refractory material as zircon in Bur. of Stds. Std. Sample 98), filter through a 7 cm. medium-open paper with a little paper-pulp into a 150 ml. beaker marked at 100 ml. and wash up to the mark.

Reduction by Jones Reductor. Activate the reductor by drawing into it 50 ml. of 5 per cent. (by volume) H_2SO_4, turn off the stop-cock, and quickly empty from the flask the water so drawn out. Then slowly draw through the reductor the 100 ml. of solution in the beaker, following it just as it leaves the "cup" with 50 ml. of 2·5 per cent. acid from the beaker, and this in turn with 50 ml. of cold water from the beaker.

To reoxidize the reduced titanium, add to the flask a catalyst(9) in the form of 0·0001 g. of $CuSO_4{\cdot}5H_2O$ (0·25 g. of $CuSO_4{\cdot}5H_2O$ dissolved in 500 ml., 5 ml. of this solution made up to 100 ml., and of this 4 ml. taken). Substitute for the stopper of the flask a cork holding an inlet glass tube going well into the liquid and draw a vigorous stream of air through it for ten minutes.

Titrate the iron with 0·05N - permanganate. Then add H_2O_2, and, according to the depth of colour given, transfer to a 250, 500, or 1,000 ml. measuring flask, to produce a weak yellowish colour for matching against standard titanium solution (0·005 g. TiO_2 in 100 ml.). It should take not more than 20 ml. of this solution from a burette to match 50 ml. of the unknown in Nessler tubes.

Obtain the percentage of Al_2O_3 by subtracting from total R_2O_3 the combined ferric oxide and titania.

(B) MODIFIED TREATMENT OF R_2O_3 RESIDUE WHEN MgO IS PRESENT

Whereas the presence of about 0·5 per cent. of lime in the clay is quite plainly shown by characteristic rosettes of needle-crystals of calcium sulphate on evaporation of the alkali extract, the presence of magnesia is not so easily detected. The analyst, however, usually knows when the presence of appreciable magnesia is possible. In that case, magnesia in the R_2O_3 residue should be determined and deducted from total R_2O_3 if accuracy in the calculation of alumina is required.

The procedure is as follows: at the end of the second extraction for alkalies transfer the R_2O_3 residue to a fairly large weighed platinum crucible, burn off the paper, ignite strongly, and weigh. Fuse with pyrosulphate. Dissolve in 10 ml. of HCl plus 40 ml. of hot water. To separate iron, titanium, and magnesium from most of the aluminium, nearly neutralize with caustic soda, bring to 100 ml. volume, heat, and pour slowly while stirring, into 100 ml. of hot 10 per cent. caustic soda solution(2, pp. 76 and 391). Boil and filter through a 9 cm. medium-open paper. Wash a few times with small lots of hot water. Reject the filtrate. Wash the precipitate back into the beaker and dissolve anything remaining on the paper by passing slowly down and through it a boiling-hot mixture of 5 ml. (only) of 1 : 1 H_2SO_4, and 25 ml. of water, catching the filtrate in the beaker, and washing with hot water. To separate iron and titanium from magnesium, add ammonium hydroxide to the hot solution until alkaline to methyl red, boil, filter through another 9 cm. paper, and wash with hot 2 per cent. ammonium sulphate solution kept just alkaline to methyl red. Determine magnesium in the filtrate.

Before dissolving the hydroxides of iron and titanium remaining on the paper, wash out the indicator present with a few small washes of hot water, then wash the precipitate off the paper into a 100 ml. beaker with about 30 ml. of hot water. Through the paper and into the beaker pass 50 ml. of hot water containing 10 ml. of 1 : 1 H_2SO_4, and bring the contents of the beaker to boiling. Now pass the solution back through the same filter, washing with hot water to a volume of 100 ml. Pass the clear cooled filtrate through the Jones reductor for determination of ferric oxide. Estimate titania, and then calculate alumina, correcting for retained magnesia. (NOTE.—The above correction for magnesia assumes that no lime also remains in the R_2O_3 after water-extraction. In the event of the clay being unusually high in lime, as detected in the evaporation for alkalies, complete extraction would be the better ensured by extracting the R_2O_3 residue further with ammonium chloride solution before igniting and weighing it. It is likewise assumed that iron is precipitated completely by caustic soda. This will be discussed in Part II of this paper.)

TABLE I.—ANALYSIS OF R_2O_3 FROM STANDARD SAMPLE 98

——	Found by Method B.	Given in Certificate.
Fe_2O_3, per cent.	2·02; 2·04	2·05 ± 0·05
TiO_2, per cent.	1·42; 1·42	1·43 ± 0·06
Al_2O_3, per cent.	25·62*; 26·68	25·70* ± 0·14

* Includes approximately 0·15 per cent. of other oxides.

Results of Analysis by Modified Treatment (B).—The results of analyses in duplicate of Bur. of Stds. Std. Sample 98, Plastic Clay, containing 0·72 per cent. MgO, are given in Table I. The MgO recovered from R_2O_3 residue amounted to 0·52 per cent. and 0·60 per cent. These percentages were therefore deducted from Al_2O_3.

Also appearing in the table are the averages, given in the certificate of analyses, of determinations by eight analysts, with variations in these determinations above and below the average. All determinations are calculated on the weight of the sample at 140° c.—the clay as analysed losing 2·29 per cent. by weight at 140° c. The accuracy is quite satisfactory.

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REFERENCES

(1) CORNES, J. J. S. (1944): A Simplified Determination of the Alkalies in Silicates. *Analyst*, *69*, 237–41.
(2) HILLEBRAND, W. F., and LUNDELL, G. E. (1929): "Applied Inorganic Analysis," New York.
(3) KNOP, J. (1924): Diphenylamine as Internal Indicator in the Titration of Iron with Dichromate Solution. *J. Am. Chem. Soc.*, *46*, 262–9.
(4) DITTLER, E. (1933): "Gesteinsanalytisches Praktikum," Berlin.
(5) MACLAURIN, J. S., and DONOVAN, W. (1908): A Rapid and Accurate Method of Estimating Iron in Iron Ores. *Trans. N.Z. Inst.*, *41*, 49–51.
(6) McNAMARA, EDWARD P. (1944): "Ceramics," Vol. III, State College, Pennsylvania.
(7) VOGEL, ARTHUR I. (1939): "Quantitative Inorganic Analysis," Longmans, London.
(8) JAKOB, PROF. DR. J. (1928): "Anleitung zur chemischen Gesteinsanalyse," Berlin.
(9) GRIMALDI, STEVENS, and CARRON (1943): Determination of Iron in Presence of Chromium and Titanium with Jones Reductor. *Ind. & Eng. Chem. (Anal. Ed.)*, *15*, 387.

(To be concluded)

NEW ZEALAND SEAWEED FOR AGAR-MANUFACTURE

REVIEW OF SUPPLIES

By L. B. MOORE, Botany Division, Plant Research Bureau, Department of Scientific and Industrial Research

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Summary

During the first three years of operations, from June, 1942, to June, 1945, the Internal Marketing Division purchased over 244 tons of dry agar seaweed (*Pterocladia lucida* and *P. capillacea*). Of this amount, more than 48 per cent. came from the North Auckland west coast, more than 38 per cent. from the Bay of Plenty, and about 12 per cent. from the East Cape district. Records from individual localities indicate that the beds are likely to continue to yield at approximately the present rate. The annual harvest could be considerably increased by opening up new areas if the need arose and local collecting difficulties could be overcome.

INTRODUCTION

IN June, 1942, collecting of seaweed for agar-manufacture began in earnest in New Zealand. Japan's entry into the war had precipitated a world-wide shortage of agar, a key material in preventive medicine and in pathology. In the face of urgent demands it was decided that agar should

be made from whatever suitable seaweed was available, though it was realized that a stable and permanent industry could be established only if both initial quantities and regeneration rates exceeded certain minima. Both small-scale-picking experiments and the first year's commercial harvest were promising,* but it was obvious that the question would need to be reviewed when more data had accumulated about actual quantities purchased.

The seaweed, belonging to two species of *Pterocladia* (*P. lucida* (R. Br.) J. Ag. and *P. capillacea* (Gmel.) Born. et Thur.), has all passed through the Internal Marketing Division, which buys from the collectors on behalf of the manufacturers. Careful notes have been kept of the net weight and place of origin of each consignment received, and records extending over the first three years of operations have been made available by the Internal Marketing Division for the present study. An analysis of the figures, combined with some acquaintance with the special features of each locality, gives for the first time a basis for appraising the continued productivity of specified areas, and makes it possible to predict the trend of total yield.

RECORDS OF QUANTITIES COLLECTED

All the agar seaweed has come from the North Island, with the following totals for different districts over three years :—

North Auckland	262,171 lb. (117·0 tons), 47·85 per cent.
Bay of Plenty	210,949 lb. (94·1 tons), 38·5 per cent.
East Coast (Hicks Bay to Mahia)	66,415 lb. (29·65 tons), 12·1 per cent.
South Hawke's Bay ..	3,743 lb. (1·67 tons), 0·68 per cent.
Coromandel and Great Barrier Island	3,379 lb. (1·50 tons), 0·62 per cent.
Taranaki	806 lb. (0·36 tons), 0·15 per cent.
Total	547,951 lb. (244·6 tons), 100 per cent.

Of this total, 55·2 tons were sent in during the first year, 89·1 tons in the second year, and 100·3 tons in the third year.

Figure 1A represents the totals graphically, and suggests a rather optimistic prognosis, since the total quantity is mounting steadily and the rate of addition to it continues to increase. Figure 2 shows, however, that this satisfactory increase results more from the opening-up of new beds than from the continued activity of those already picked over. Figures 1B and 1C provide records of performance of rather well-defined restricted stretches of rocks over periods of eighteen months to three years. The graphs of Fig. 1B show several striking features common to three richly productive areas : (1) marked seasonal pattern with flattening of the curve in winter and spring and sharp rise in autumn ; (2) collecting slow over the first autumn, reaching a maximum in second autumn, and considerably less in third autumn. Raukokore-Waihau Bay alone shows the next phase, and the strong autumnal increase here indicates that the drop in the previous autumn's figures was due to temporary depletion only or to some other cause.

In the graphs of Fig. 1C seasonal differences are much less marked. The curves for Herekino and Maketu may well be expected to flatten more strongly as they enter their third winter-spring period. Ahipara, after building up steadily throughout the whole of the first full year, will probably also show reduced activity. Te Kaha is included as an example of a district where some essential condition is not especially favourable. An energetic initial

* MOORE, L. B. (1944) : *N.Z. J. Sci. & Tech.*, *25*, 183–209.

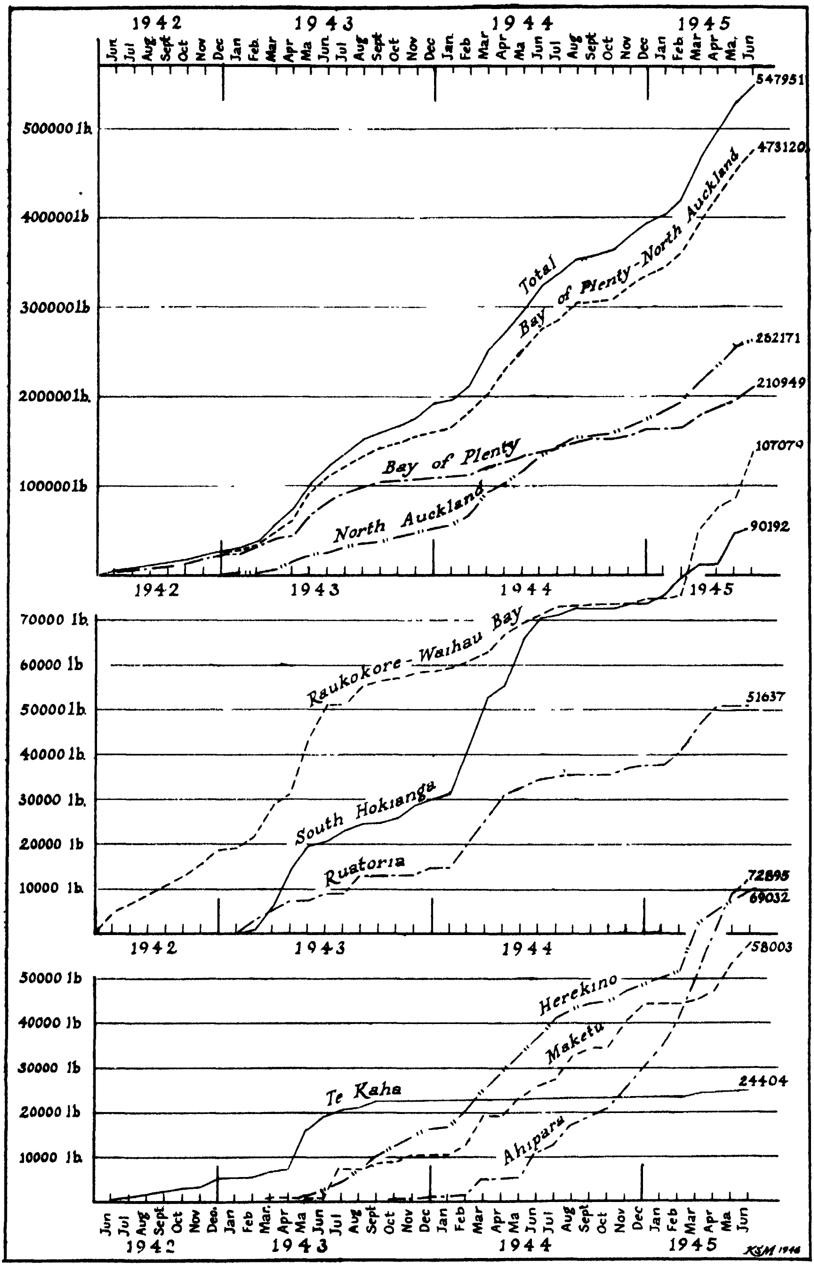

FIG. 1A, B, and C.—Graphs showing total weight of agar seaweed received from each of various sections of the coast up to the end of each month.

onslaught accounted for all easily gathered weed. It will be interesting to see how long it is before collecting again becomes an attractive proposition in the considerable number of localities that show a pattern similar to that of Te Kaha.

NOTES ON INDIVIDUAL LOCALITIES

Raukokore-Waihau Bay.—This portion of the extreme north-eastern end of the Bay of Plenty stretches from the Raukokore River mouth to Waihau Bay, a distance of four or five miles by road and rather more along the coast itself. Various short lengths of sandy beach divide up the long stretches of jagged greywacke rocks that extend out into shallow reefs below low-tide level. There is a hard-working Maori population living close to the coastal fringe, the single school at Raukokore having some 90 pupils.*

The weed is principally *P. lucida*, collected from drift and by wading, either from the shore or from small boats amongst the outer rocks. Transport is by horse or by bullock cart for the wet weed, with motor-lorry to take dry weed to boat or rail. Individual collectors despatch their own weed, packed in wool-bales. Nearly 48 tons have been sold from this area in three years.

Maketu.—In the middle Bay of Plenty, between Kaituna River mouth and the Waihi Estuary, is a short rocky headland, with about two miles of frontage to the sea. East and west of it sandy beaches stretch for many miles. From the boulders at the cliff base a rocky intertidal platform extends out a few hundred yards. The famous Maori village of Maketu nestles against the headland, its size indicated by a school of 114 pupils.

The seaweed collected is *P. lucida*, and a large part of it must come in drift or from extensive off-shore beds. The short length of headland could hardly have produced the large quantity (nearly 26 tons) that has been purchased from Maketu within the last two years. The practice here is to pack the dry weed into corn-sacks holding 60 lb. to 70 lb. each, and to send by lorry to the rail at Te Puke. Large consignments are typical, and half a ton or even more than a ton—*e.g.*, a railway truck full—may come at one time under one name.

Ruatoria District.—Ruatoria, itself five miles inland, is the centre for the twelve miles of coast from Reporua (sixteen miles south of East Cape) to Waipiro Bay. Channelled intertidal platforms of papa rock are typical, though there are harder outcrops—for instance, at Tuparoa. Collecting has been done mostly by two small Maori communities living right on the coast, Whareponga with 30 pupils at the school, and Tuparoa with 55. Whareponga has remarkable beds of *P. capillacea*, left almost bare at low spring tide. Elsewhere *P. lucida* is common and is collected by wading and some diving. Dry weed packed in wool-bales goes by lorry to the coastal steamer. Collectors sell individually, though there is some co-operation between them, especially at Whareponga. Nearly 23 tons have gone forward in less than two and a half years.

South Hokianga.†—On the North Auckland West coast, this area stretches from about three miles south of Hokianga Heads a distance of some seven miles to beyond the Waimamuku River. Long stretches of sand are broken by extensive rock platforms, reaching from half-tide to below low-tide with shallow off-shore reefs. There is a considerable Maori population (170 pupils in four schools), but the majority live some distance from the coast, and ride out for seaweeding, here called "agaring."

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* Roll numbers, kindly supplied by the Education Department, are considered to be the best available indication of the size of settlement.

† The Opononi area within Hokianga Harbour is not included under this heading.

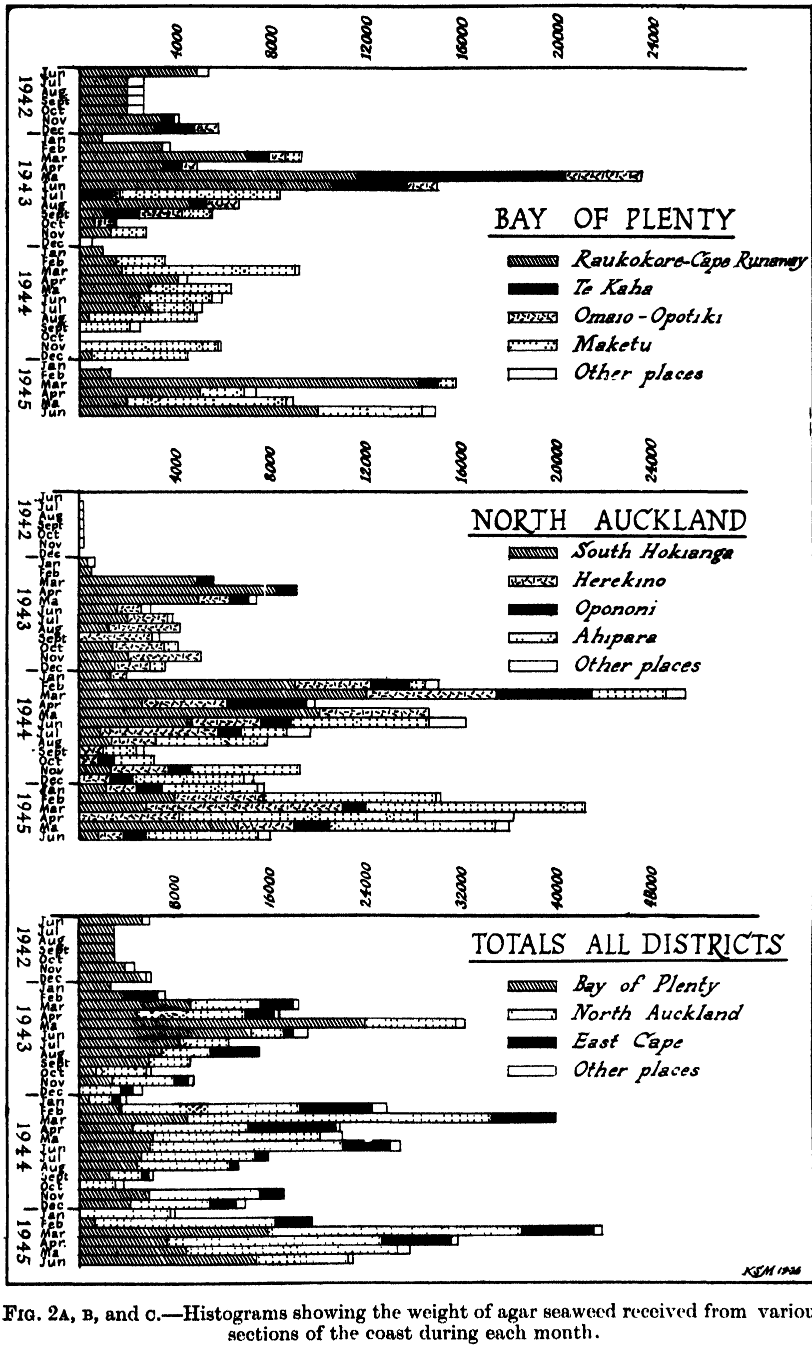

FIG. 2A, B, and C.—Histograms showing the weight of agar seaweed received from various sections of the coast during each month.

The weed is almost entirely *P. lucida* obtained from drift and by wading and diving in water up to 4 ft. or 5 ft. deep. No boats are used. Wet weed is carried on horse-back, and, after drying, most of it is pressed in a hay-baler, and wired for lorry transport to boat or rail. Weed is consigned by individual collectors, and more than 40 tons have been sold in less than two and a half years.

Herekino District.—On the North Auckland west coast there is a rocky stretch of about eight miles between the mouths of the Herekino and Whangape Harbours. If Mitimiti, five miles south of Whangape, may be taken as representative, conditions are not unlike those at Waimamuku farther south and Ahipara farther north. The scattered Maori population is served by schools at Whangape (85 pupils), Pawarenga (107 pupils), and Herekino (47 pupils). Though *P. capillacea* is present, the weed sold is almost all the robust west coast *P. lucida*, forwarded chiefly through the Herekino storekeepers. Nearly 31 tons have come from this district in just over two years.

Ahipara.—The Ahipara collecting area lies immediately north of the Herekino stretch of coast, and the two may even overlap. Weed from some miles south of Reef Point probably goes out through Ahipara, giving a total length of rocky coast for this district of probably less than ten miles. Intertidal platforms and shallow offshore reefs jut out of the predominating sand. Few Maoris live near the rocks, but at Ahipara there is a large settlement with 234 pupils at the Native school. Those who come from a distance set up camps on the spot while collecting is in progress.

P. lucida is the chief weed, collected by wading and diving or from drift, but without boats. It is dried on the grass just above the beach, taken away by horse or sledge, and sold almost entirely through self-appointed local agents. In the eighteen months after collecting began 32½ tons were sold.

DISCUSSION AND CONCLUSIONS

Factors affecting Season of collecting and Time of Sale.—The seasonal influx of weed into the Internal Marketing Division store is brought about by a combination of circumstances. Once the weed is collected and dried it may be stored away indefinitely without spoiling. The time of sale has therefore no obligate relationship to the time of picking, except where storage space is at a premium or money is urgently needed. Naturally, most of the picking is done in summer and autumn, when the water is warm and air-drying is easy, but packing may be delayed until the weather deteriorates. In farming districts there is little spare time for seaweeding until after Christmas, when the flush of the dairying season is over and the shearing is finished. Lorry and steamer transport, when preoccupied with the season's wool-clip, cannot cope with seaweed also, and this accounts in part for the autumn accumulation.

Relation of Size of Harvest to Length of Coast.—Large quantities of weed have been collected and apparantly can continue to come forth from quite short lengths of coast-line. A continuing average of 15 tons per annum per five to ten miles of productive coast seems quite possible in each of the following localities: Raukokore-Waihau Bay, Maketu, South Hokianga, Herekino, and Ahipara. The gross value of 15 tons of seaweed is £1,680, which works out at from £8 to £20 per school child in the district.

Prospects:—

(*a*) *Areas already worked.*—On the basis of the figures given and the trend of the curve of production, there is reasonable ground to hope that the areas already being exploited can maintain the average of the last three years—*i.e.*, at least 80 tons a year.

(*b*) *Areas not yet fully exploited.*—The great bulk of the agar seaweed at present being utilized comes from a very small proportion of the coast that is known to be *Pterocladia*-bearing (*cf.* Moore, 1944, Fig. 5). Probable reasons for lack of interest in other districts are: (1) Ignorance of the potential value of the beds where sporadic collecting was regarded as a minor patriotic effort and did not demonstrate the full possibilities. (2) Insufficient people of the right kind in suitable places. (3) The inhospitable nature of parts of the coast; *Pterocladia* grows in some places where collecting would be really dangerous. (4) Transport difficulties, especially wartime shortage of benzine for private vehicles. (5) Man-power shortage and preoccupation with other activities operate especially in the vicinity of towns—*e.g.*, good beds of weed have attracted little attention near Tauranga, Whakatane, Tokomaru Bay, and Gisborne.

The general conclusion is that present supplies will be approximately maintained from the same districts. To increase these by exploiting new areas might not be very easy, but could probably be done if it became necessary. The industry should not fail for want of raw material; its future depends more on economic conditions, and prices in the world market.

THE SEISMIC GEOMETRY OF A VOLCANO SUCH AS RUAPEHU

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Summary

For a volcano of the size of Ruapehu, the problem of the location of the foci of seismic disturbances is discussed. A group of hypothetical stations is used to consider the geometrical principles involved, the layout of stations for particular methods, and the bearings of instrumental performance and initial assumptions on the accuracy attainable. Remarks are made also on the problem of early location of incipient activity in the thermal region.

INTRODUCTION

THE recent activity of Ruapehu has again called attention to the need for studies of the New Zealand volcanic and thermal districts by geophysical methods; one object would be to give warning of an imminent eruption, which has been shown from studies in Hawaii and in Japan to be quite feasible, given the necessary instruments. Information would be required concerning (*a*) the general geophysical phenomena during periods of quiescence, and (*b*) the phenomena which would characterize the preparations for an eruption, the maximum activity, and the return to quiescence. Changes of ground or spring temperatures, changes in the magnetic field, tilting of the ground or changes of level, and seismic disturbances are symptoms of approaching activity that have been used elsewhere. The present paper will deal with some preliminary aspects of the application of seismic methods to the local conditions.

The types of seismometers most suitable for the purpose will depend on a number of factors, including the magnitudes and periods of the shocks to be expected, the geometrical methods to be used in the location of foci, the openness of scale and accuracy of time-measurement desirable for satisfactory application of these methods, and such practical aspects as housing, accessibility, expense, and so on. While the experience of other countries is available for some of these points—*e.g.*, Jagger(1), Imamura(2)—the development of seismometers has been very rapid in recent years, and it is probable that further applications of electronic methods will open up new possibilities for close-range work. The present study is concerned mainly with close-range methods, and will indicate the likely requirements for the performance of instruments and the layout of stations to give a desirable accuracy in the location of foci. Ruapehu has been taken as an example but the principles should apply in general to any volcano of about the same size.

SEISMIC METHODS

Studies of the S-P interval and its relation to Hawaiian travel-times and to the location of foci were made by Austin E. Jones(3): the pulses considered, P_g, P^+, and P_n, with the corresponding S-pulses, are those involving crustal layers some tens of kilometres in thickness; recordings were available up to 90 km. The eruption of Tarawera in 1886 was preceded by earthquakes strong enough to awaken sleepers in the Rotorua district, at distances of some 25 km., and these could no doubt have been recorded at 100 km. by suitable instruments; but from the feebleness of the seismic disturbances so far observed in eruptions of Ruapehu and Ngauruhoe, it is doubtful whether they could be recorded in detail at such a distance, and possibly the distances of seismometers from probable epicentres would have to be within, say, 20 km. For such short-range work the use of even an S_g-P_g interval would be open to objections: the first pulse to arrive might well have travelled through only the andesitic material comprising the volcano, delays in the apparent starting-time of either S or P waves would involve considerable complications, a surface wave might arrive before the first S, and so on. Therefore, although the instrumental difficulties would be greater, in that comparisons of the times of arrival at different stations would be required, it appears worth while to consider the possibilities also of "seismic sound-ranging" methods, using the differences in times of arrival of the first pulse (or any other pulse identifiable with certainty) to locate the focus. As the focal depths could be of the same order of magnitude as the distances, a theory of sound-ranging in three dimensions is required, and in the following is considered for stations located on the volcano within less than eight miles from the summit. It will be assumed that the rays will travel in straight lines with a constant velocity. In view of the straightness of the line connecting the several explosion craters, Ruapehu, Nga Puna a Tama, Ngauruhoe, Tongariro (South Crater), Blue Lake, Sulphur Lagoon, there is some presumption that epicentres would be over the fissure indicated by this line, but for the present it will be assumed that epicentres are possibly distributed anywhere on the mountain. Before going further, however, it may be useful to consider within what distances from the summit the rays are likely to have passed entirely or almost entirely through andesitic material.

GEOLOGICAL FEATURES OF RUAPEHU

The N.Z. Geological Survey map of the area shows the visible rocks adjacent to the volcanoes, which occupy a graben between the Kaimanawa Range on the east, composed of greywacke and argillite of Palaeozoic or

Mesozoic age, and similar rocks forming the Hauhaungaroa Range on the north-west, and the block Taurewa farther south. The depression is partly filled by Tertiary mudstones, &c., the surface of which dips gently in the direction of Wanganui, and is at a height above sea-level of some 3,800 ft. at Hauhungatahi, where the andesite of this subsidiary to Ruapehu is seen to cover it. The andesites have thus come up presumably through some channel or fissure in the down-faulted greywacke and made their way through the Tertiary sediments. Some doming up and blowing out of the

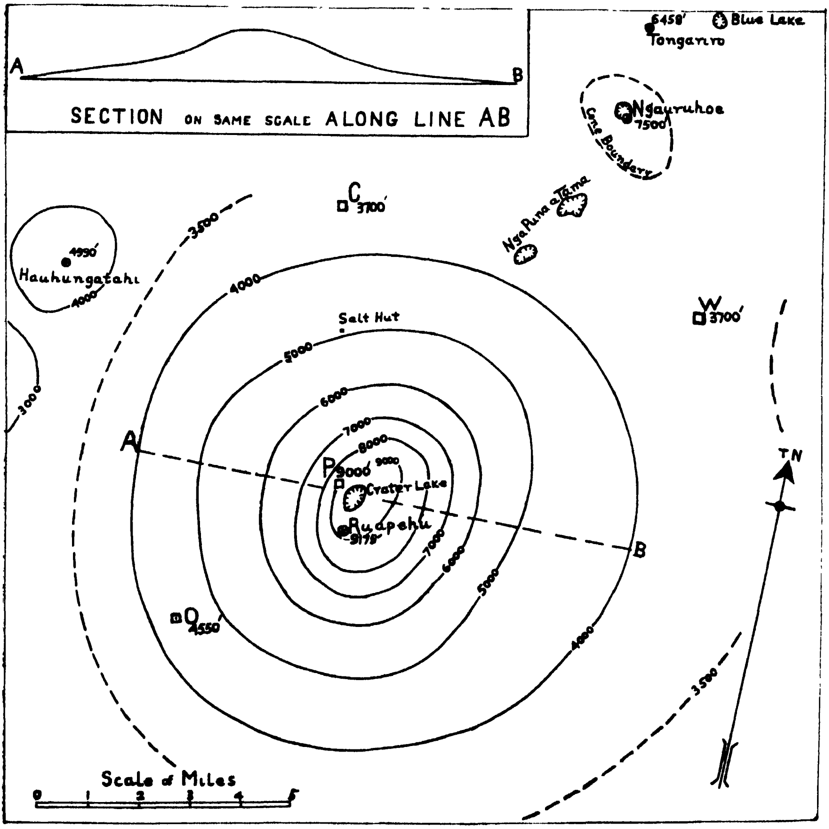

FIG. 1.—Approximate contours of Ruapehu, with an E.-W. section above 4,000 ft.

sedimentary rocks could be expected. Lava and fragmental material has then flowed or been deposited on the surface of the Tertiaries. What the proportions are of each can hardly be estimated, but perhaps where the fragmental material has been consolidated there will not be a great difference in the seismic velocities.

Approximate contours of Ruapehu, derived from the barometric and trigonometrical station heights given on the Geological Survey map, are shown in Fig. 1, and inset is an approximate E.-W. section showing the shape of the volcano inside the 4,000 ft. contour. For seismic foci below the summit it is apparent that at stations in the vicinity of the 4,000 ft. contour the horizontal component of a P-wave would be greater than the

vertical for focal depths less than about five miles below the summit, and if attention was being concentrated on the column thus defined, the best results for P-waves would be obtained from horizontal-component seismometers, each oriented in the direction of the summit.

Outside the boundaries of the volcano the Tertiary system may have a thickness of some thousands of feet. It seems that with a network of stations inside, say, the 3,500 ft. contour the rays recorded from the shallower foci below the area defined by this contour could, for a working assumption, be taken as having passed mainly through andesitic material, or perhaps partly through greywacke in which the velocities would not differ greatly from those in the andesitic material; while outside this contour a ray may have passed through appreciable thicknesses of Tertiary mudstone, in which the velocities would presumably be smaller. While general values for seismic velocities in different types of rocks are available, it would be more satisfactory, if opportunity offered, to determine them directly, and at the same time to get what indications of structure are obtainable, by the usual methods of seismic prospecting.

SEISMIC GEOMETRY

A. *General Principles*

The close-range network of stations would be essential if it was desired to locate the focus of disturbances just before an eruption; it would be desirable to know the focal depth with an accuracy of, say, 1,000 ft., and this could evidently not be achieved by a network of stations at distances, in a nearly horizontal direction, of the order of tens of miles, even if the shocks were powerful enough to be recorded. On the other hand, the close-range system would not locate the foci efficiently if they were at depths greater than, say, the average radius of the system, and a network of radius of the order of tens of miles would be needed; here the complications of the thicknesses of and velocities in the crustal layers would come in. And to complete the picture, the services of the regional network of seismological stations are required to place the foci of depth one hundred to two hundred miles which are now known to occur below the thermal regions, although it is not yet known to what extent, if any, they are related to the surface vulcanicity. For the intermediate group the methods described by Austin Jones(3) would be applicable, and we consider below methods for the close-range group.

B. *Description of Methods*

Assuming rectilinear propagation and uniform velocity, methods may be grouped in three categories :—

(*a*) When the slant distances from focus to stations are determined from the records. These may be obtainable from S-P or other pulse-intervals, and then do not require the measurement of absolute times at the stations, but the methods are complicated by the factors mentioned above, reliable identifications of the pulses, delays in starting times, &c., and may not be readily applicable to the close-range work.

(*b*) When the differences in the times of arrival of a pulse at pairs of stations are obtained from the records, as in sound-ranging. A knowledge of the velocity is required, and the absolute time must be known with suitable accuracy on each record, unless it can be arranged for all stations to record on the same sheet or film.

(*c*) The ratios of differences as obtained for (*b*) can give the position of the focus, without a knowledge of the velocity. One more station is required than in (*b*).

Direct mathematical treatment involves the solution of equations too cumbersome for practical use—for example, in (*b*) the equations are of the form—

$$\left\{(x-x_1)^2+(y-y_1)^2+(z-z_1)^2\right\}^{\frac{1}{2}}-\left\{(x-x_2)^2+(y-y_2)^2+(z-z_2)^2\right\}^{\frac{1}{2}}=\mathrm{A}$$
$$\left\{(x-x_1)^2+(y-y_1)^2+(z-z_1)^2\right\}^{\frac{1}{2}}-\left\{(x-x_3)^2+(y-y_3)^2+(z-z_3)^2\right\}^{\frac{1}{2}}=\mathrm{B}$$

where x, y, z are the co-ordinates of a focus, x_1, y_1, z_1, &c., those of observing stations, and A, B are the distance-differences deduced from the observed time-differences. Graphical methods are more feasible.

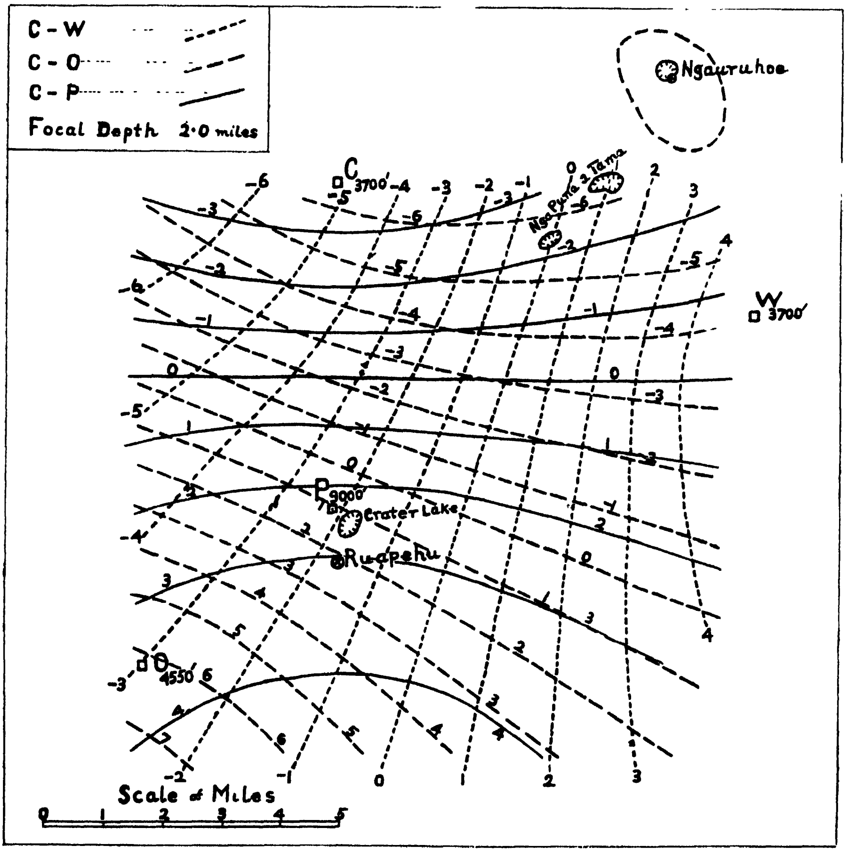

FIG. 2.—Lines of equal differences, in miles, of slant distances from three pairs of stations. Focal depth, 2·00 miles.

The principles can be illustrated by considering a sample group of stations within the 3,500 ft. contour, and for the purpose one has been assumed at Paretetaitonga (one of the summit peaks, alongside the active crater) and one each at the Chateau, the Ohakune, and the Waihohonu mountain huts, as representing accessible sites distributed around the perimeter. (These are denoted respectively by P, C, O, and W on the diagrams, and are at heights of 9,000, 3,700, 4,550, and 3,700 ft. above sea-level.) For a grid

of points at one-mile intervals over a nine-mile square, the slant distances have been computed for several focal depths (focal depths are with respect to sea-level, positive below), and form the basis for the diagrams. The distance-differences can be converted to the time-differences which would be measured, by using an appropriate value for the velocity of the wave in andesite. For a P-wave, this would be of the order of three miles per second. The mile has been retained as the unit, for convenience in working from the Geological Survey map, and the distances have been computed to the nearest hundredth.

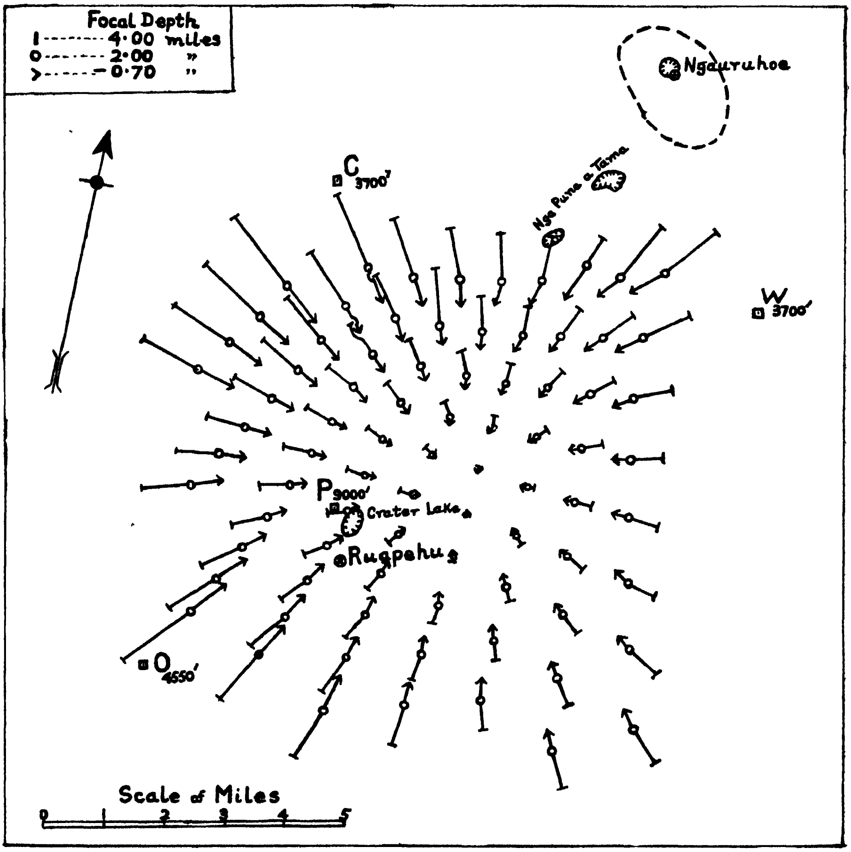

FIG. 3.—Variations with focal depth of the positions of epicentres as determined from the intersections of the same-valued distance-difference lines. for C–O and C–W.

A first consideration is that the results from three stations, or from any number of stations in the same plane, cannot distinguish on which side of the plane passing through the stations an origin would be (unless observations of vibration-directions were made), although frequently the ambiguity would not arise, on account of the restricted portion of the mountain on one side of the plane. Again, for stations all in one plane, methods based on distances (or their differences) would not be very sensitive to variations of the focus in directions at right angles to the plane if the distances were large in comparison with the departures of the focus from the plane. Thus it would be desirable to have at least one station well outside the plane of three of the others.

C. *Scale and Accuracy of Time-measurement*

For such a close-range network, the time-measurements would need to be of the same order of accuracy as those required for the seismic methods of geophysical prospecting. A P-wave will travel some 200 ft. in a hundredth second, and as positions and depths will in general be derived from the intersections of curves each subject to the limitations of time-measurement, placements will not usually be accurate to 1,000 ft. unless the times are

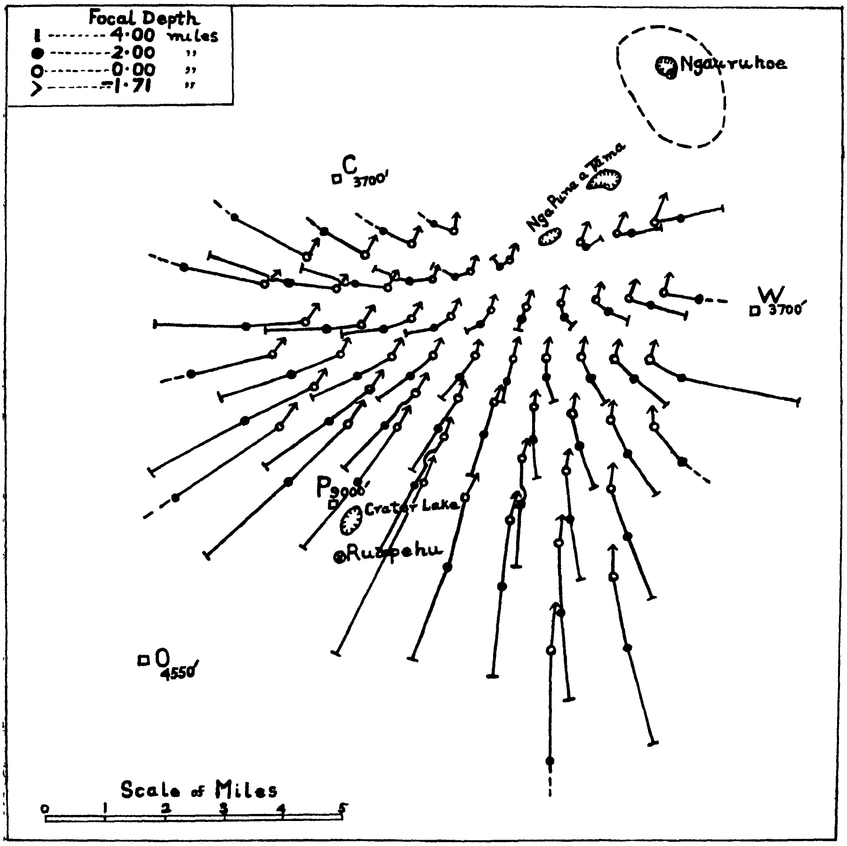

FIG. 4.—As for Fig. 3, but for C–W and C–P. Epicentres represented by the heads of the arrows, for focal depth −1·71 miles (−9,000 ft.), would be real only when inside the 9,000 ft. contour.

accurate to about a hundredth second. This, of course, raises the practical difficulty of continuous recording on such an open time-scale: to discuss this and other matters of technique is beyond the scope of this paper, but it is thought that quite practical and reasonably inexpensive methods can be devised. As further errors in location will no doubt arise from the imperfections of the theoretical assumptions, this need for the most accurate time-measurements feasible is further emphasized. Any method of accurate location will depend, of course, on the impulse being sharp enough to be measurable to the requisite degree of accuracy.

D. *Some Illustrative Diagrams*

(*a*) *Distance-differences.*—Diagrams such as those reproduced can be drawn remarkably quickly, once the slant distances are computed for a group of stations, but only a few can be reproduced and briefly discussed here. Figure 2 shows a set of curves of equal distance-differences, in miles, for the stations grouped in three pairs, for the focal depth 2·0 miles (below sea-level). For a velocity of three miles per second the intervals of one mile correspond to time-differences of one-third second. For the focal

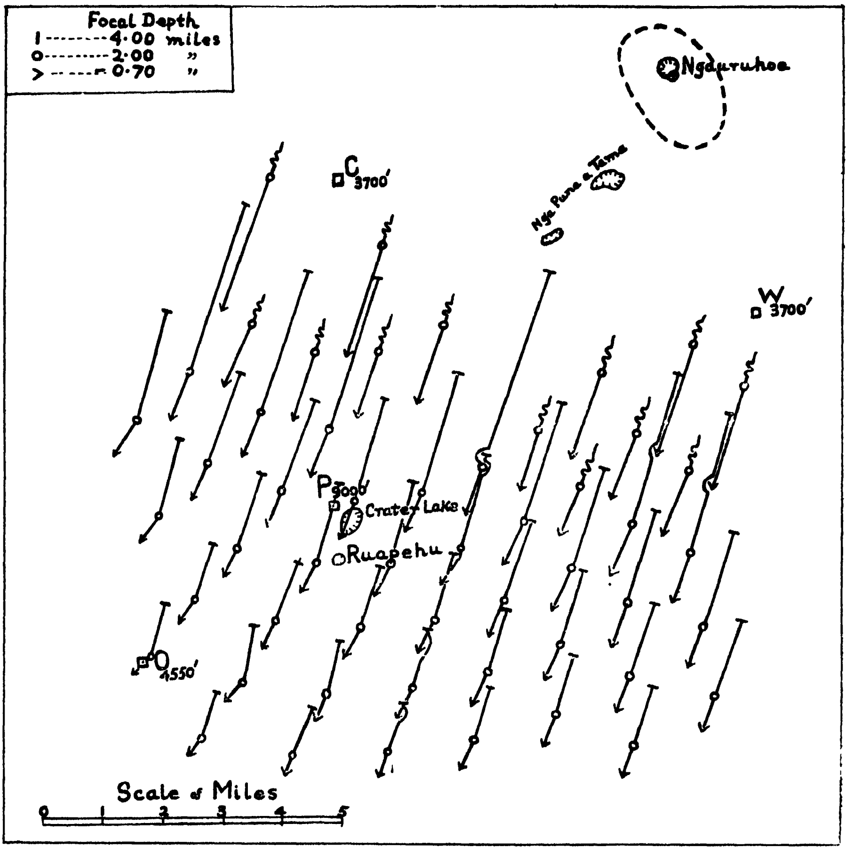

FIG. 5.—Variations with focal depth of positions of epicentres as determined from intersections of the same-valued slant-distance lines from C and W. The spirals denote that the particular intersections are non-existent for the deeper focus.

depth chosen, the intersection of the two curves derived from three stations will give an epicentre. Where the curves are most closely spaced, and where intersections are most nearly at right angles, the placings will be least subject to errors of measurement.

The epicentres obtained from the same values of the distance-differences will be in different positions for other focal depths, and Fig. 3 shows the magnitudes and directions of the displacements, for the differences C–W and C–O, as the focal depth varies. The tail of each arrow represents an epicentre obtained by the intersection of two particular distance-difference curves for a focal depth of 4·00 miles. The head is the intersection of the

curves for the same differences for a depth of —0·70 miles (the level of C and W), while the intermediate point is for a depth of 2·00 miles. For higher foci—that is, between —0·70 and the summit, —1·71—the epicentres, except for the slight departure of O from the level of the other two, would commence a return journey back along the same arrows. Within the limits of focal depth from —1·71 to 0·31, it can be seen that the placing of the epicentre would not be greatly affected by the changes of focal depth, but, on the other hand, the actual determination of the focal depth would give

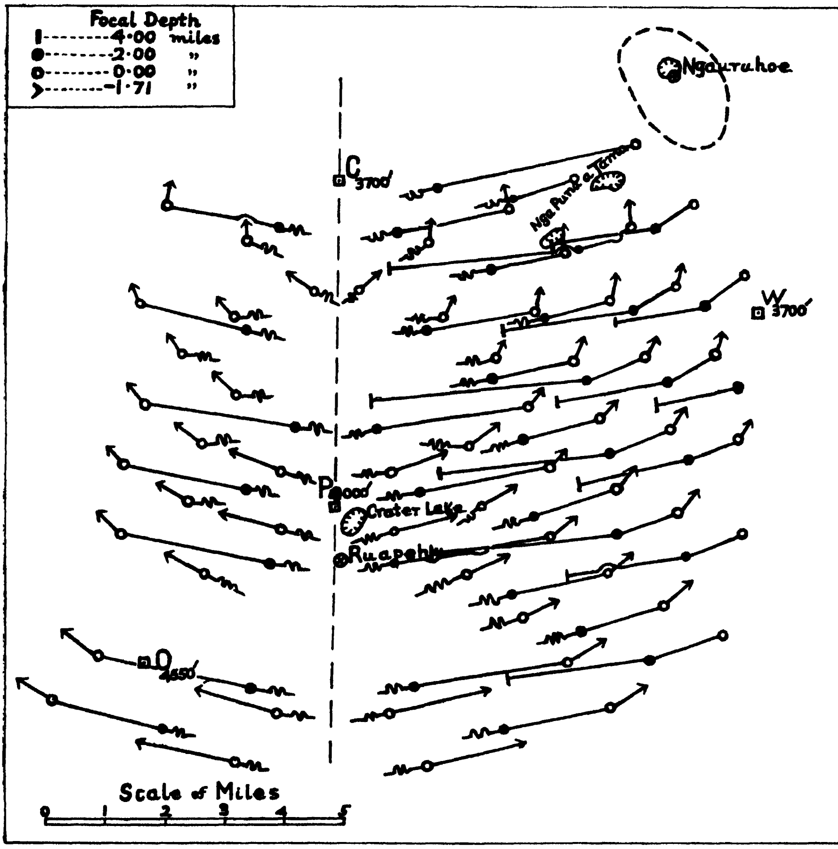

FIG. 6.—As for Fig. 5, but for C and P, and foci up to —1·71 miles (—9,000 ft.).

some difficulty—the focus might be on either side of the plane through the three stations, and also variations of, say, 1,000 ft. in the focal depth would make but little difference in the slant distances over the range mentioned.

The arrows all point approximately in the direction of the point equidistant from the three stations, and reach their minimum length at about this point (if the level of all three stations was the same, the length would then be zero). A fourth station, giving with two of the first three an intersecting arrow, would be required to give the epicentre, but it can be seen that if the active area was restricted to a small column below the summit, and if three stations were distributed at equal distances from the centre of this area, the three stations only could give a very short line as the locus of the epicentre, though not an estimate of the focal depth.

In Fig. 4 the same procedure has been followed, with station P, near the summit, instead of O, and the range of focal depth is from —1·71 to 4·00 miles. The arrows are now several miles long in the vicinity of the crater, illustrating the greater sensitivity of this group in respect of focal-depth determinations in this vicinity, with smaller sensitivity in respect of epicentral determinations. They are reasonably straight and constant in direction here, but are sharply curved, though shorter, in the neighbourhood of C and W, where there would be some trouble in drawing them accurately.

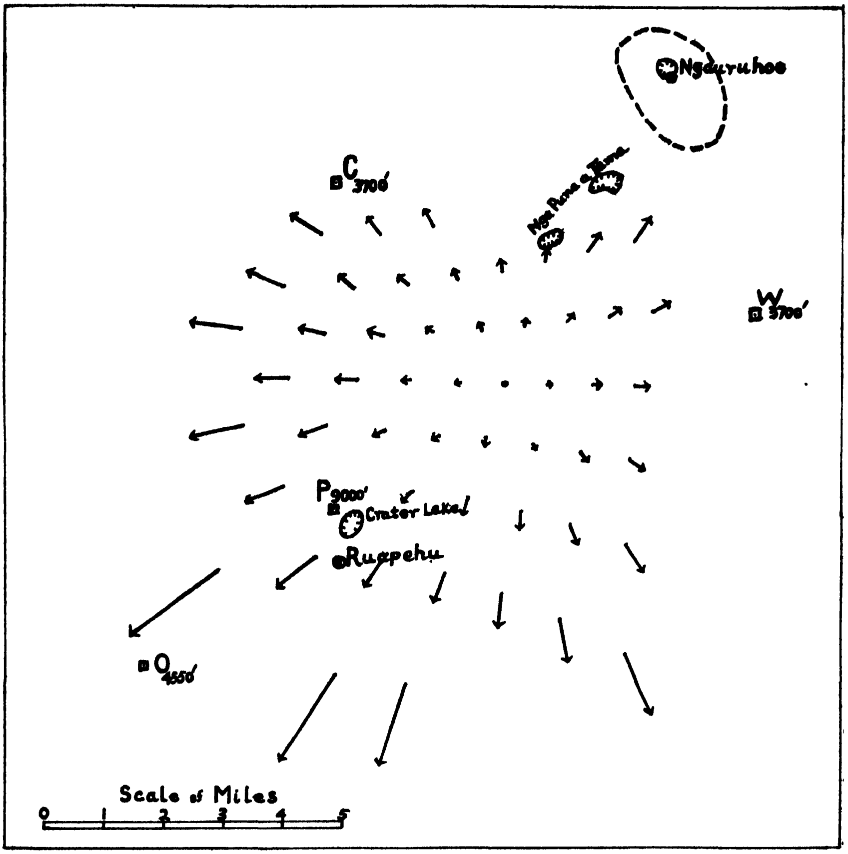

FIG. 7.—Displacements of epicentres as determined by intersections of distance-difference lines, for C–W and C–P, when all distance-differences are increased by 10 per cent. Focal depth, 2·00 miles.

Superposition of Figs. 3 and 4 shows the angles of intersection of the two sets of lines as more favourable (more nearly approaching a right angle) from the crater for several miles in the N.W.–N.E. quadrant, and poor within two miles from N.E. round to S. With P fixed, other groupings of the other three stations would show similar strengths and weaknesses, and to cover all the area adequately it might be desirable to have a fifth station.

(*b*) *Distances.*—If the slant distances can be determined from S-P or other intervals on a single record, which, if practicable, is a simpler method involving no comparisons of absolute times and requiring one fewer station. When all stations are on the same level, the method developed by Isikawa,

and quoted by Austin Jones (*loc. cit.*, p. 41), is applicable. Arcs are drawn from two stations with the respective focal distances as radii, and the epicentre lies along the chord joining their points of intersection, and similarly for another pair of stations. When the stations are at different levels, however, a complication arises, and the method here employed has been as follows: for each of several focal depths, circles showing slant distances from each station have been drawn (the radii having been computed for slant distances of one, two, three, &c., miles) and the intersections of

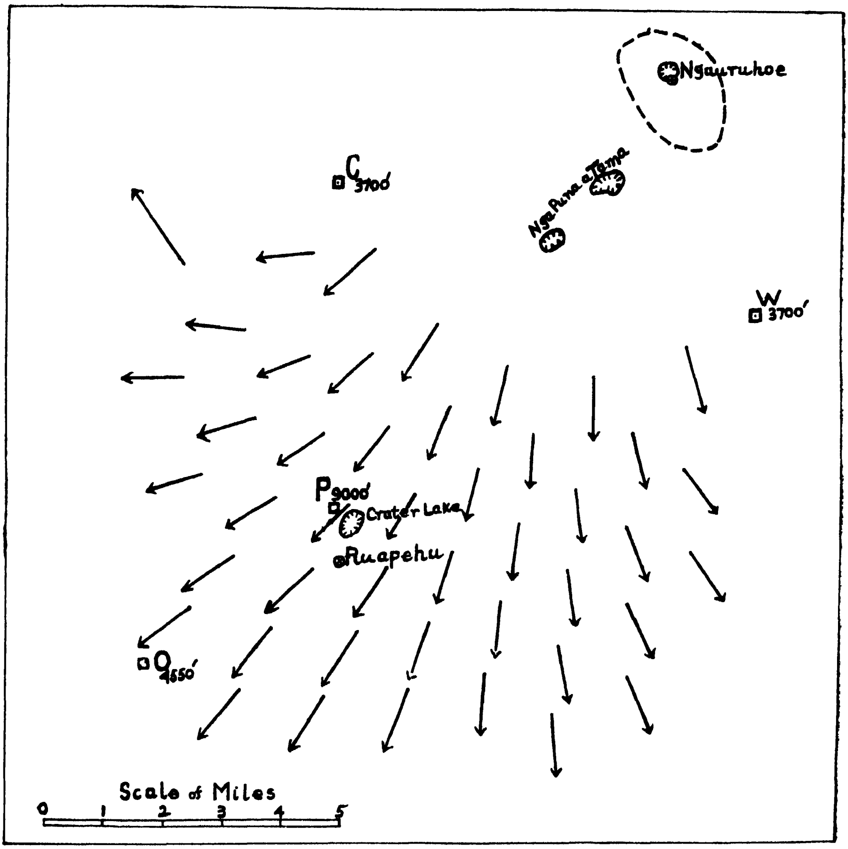

FIG. 8.—Displacements of epicentres as determined by intersections of distance-lines from C and W, when all distances are increased by 10 per cent. Focal depth, 2·00 miles.

these circles plotted for each of the focal depths. We thus get diagrams of the type of Figs. 5 and 6. In some cases intersections obtained for particular values of the slant distances at shallow focal depths will not exist for the deeper foci; this has been indicated by the spirals on the arrows. Figure 5 shows loci of epicentres for C and W, two stations on the same level, and Fig. 6 for C and P, at a difference of level of 5,300 ft. Such diagrams are symmetrical about the line joining the two stations and for stations on the same level, also about the line bisecting this at right angles, the general direction being parallel to the latter (some small errors in drawing

have crept into Fig. 5); but for stations on different levels the latter symmetry does not hold, and the arrows show considerable curvature over the smaller focal depths. In both cases intersections are poor in the vicinity of the line joining the two stations.

Superposition of Figs. 5 and 6 shows good angles of intersection over all the area, reflecting approximately the angle between CW and CP.

The arrows get shorter in passing outward from the line joining two stations, but are everywhere more than a mile long, so that the method, for two stations only, could not place an epicentre very closely; there would, of course, be two arrows to choose from, but the ambiguity might be removable from other evidence.

(c) *Ratios of Distance-differences.*—The ratios of the distance-differences will be the same as those of observed time-differences, on the assumption of uniform velocity, and theoretically this gives a means of obtaining the epicentre and the focal depth without knowing the velocity. An extra station is required as compared with method (a), making four as a minimum. Space limitations prevent the reproduction of illustrative diagrams here; in parts of the area they are readily drawn, showing but little curvature, but when the ratios approach infinity or the indeterminate value O/O, a greater density of points is required than the one-mile grid used for the other curves.

(d) *Effects of Errors.*—Some idea of the effects of possible errors, when the distances or distance-differences are affected by imperfections of time-measurement or by the assumption of a wrong velocity, can be gained from Figs. 7 and 8. Figure 7 shows, for the distance-difference method, the displacements of a given set of epicentres, derived from the intersections of distance-difference lines for C–W and C–P, when all the differences are increased by 10 per cent., as they would be, for example, if the velocity assumed was too large by 10 per cent. of its true value. The displacements are quite small in the vicinity of the central point. Figure 8 shows the type of displacement when the slant distances, as derived for example from S-P intervals, are overestimated by 10 per cent. The displacements are all nearly of the same value, about a mile, for the intersections of distance-lines from C and W. The focal depth in both cases was taken as 2·0 miles; other focal depths could be dealt with in the same manner.

CONCLUSION

The foregoing remarks, dealing mainly with close-range work on a single volcano, refer to the instrumental performance and the layout of stations suitable for the detailed study of that volcano. Another problem would be to recognize as soon as possible, in an active region, the particular volcano (or perhaps a hitherto quiet locality) showing signs of subterranean activity that might lead to an eruption. For example, in the Rotorua district, further activity might develop anywhere along the rift-line between Tarawera and Rainbow Mountain, or possibly elsewhere in the district: the next eruption in the Ruapehu area might be from Ngauruhoe or from Tongariro. The density of seismic stations suitable for this problem must depend both on the magnitude of the disturbances—that is, the distance at which they could be satisfactorily recorded—and on the depth at which they are first manifested—as remarked above, no accurate estimate of the depth could be made from stations very far away compared with the depth. Information on these points is lacking for the local conditions, but if a long-term programme of research was visualized, it would be well to collect some preliminary data by scattering half a dozen sensitive instruments

over the thermal area, with portable instruments available to take to any area showing activity, and keeping them continuously recording over a period of years. When the distances from epicentres are of the same order as the total thicknesses of crustal layers, data for assessment of the velocities and thicknesses of these layers become essential. In addition, there may be the complications of the roots of the mountain ranges, variations in velocities along and across the structural grain of the country, bodies of magma which may transmit S-waves imperfectly—all of which would contribute to the difficulties of accurate location. In some respects the P-difference methods avoid these complications; a preliminary study of medium-range work on these lines has been made by the writer(4) giving some of the geometrical principles involved.

REFERENCES

(1) JAGGAR, T. A. (1920): Seismometric Investigation of the Hawaiian Lava-column. *Bull. Seism. Soc. Am. 10, No. 4.*

(2) IMAMURA, A. (1937): "Theoretical and Applied Seismology." Maruzen Co., Tokyo.

(3) JONES, AUSTIN E. (1935): Hawaiian Travel-times. *Bull. Seism. Soc. Am. 25, No. 1.*

(4) JONES, W. M. (1945). The Application of P-difference Methods to New Zealand Local Seismology. *N.Z. J. Sci. & Tech., 26 (Sec. B)*, 359.

A NOTE ON REARING *ANOBIUM PUNCTATUM* DE GEER

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Summary

The description of a new technique for inducing *A. punctatum* to oviposit on smooth wood surfaces is recorded. The usefulness of the method lies in the possibility of being able to count every egg laid, so increasing the value of analytical interpretations of the results. Comparisons are made with previous techniques.

INTRODUCTION

THE following notes continue the investigations to discover the optimum conditions for rearing *Anobium punctatum* de Geer for use in testing the efficiency of the various types of preservatives for protecting timber against wood-destroying insects. The present paper is an account of a method evolved to induce *A. punctatum* to ovipost on wooden blocks with smooth surfaces in order to facilitate counting of eggs. This beetle normally lays its eggs in old emergence holes, cracks, crevices, or rough surfaces, and in such situations it is a very difficult matter to count all eggs, and consequently the analyses of figures for oviposition, hatching, survival, &c., are inaccurate. Using the present technique there is no difficulty in the way of accurate analysis, and the method is simple and rapid. Results are compared with previous experiments to give some guide as to the merits of this new treatment.

Materials used.—The timbers involved in the experiments were kiln-dried insignis pine (*Pinus radiata* D. Don.) and tawa (*Beilschmiedia tawa* Benth and Hook f.), and air-dried *P. radiata*, kahikatea (*Podocarpus dacrydioides* A. Rich.), and rimu (*Dacrydium cupressinum* Soland.) in blocks either 2 in. by 1 in. by 1 in., or 3 in. by 1 in. by 1 in. Fine-mesh organdie muslin free from projecting hairs was used in varying widths and lengths for wrapping round the blocks, some of which also had spirals of No. 40 cotton beneath the muslin. The only other material was flour-paste such as that used by paper-hangers, prepared by mixing flour into a smooth paste with cold water and then pouring boiling water into it until it becomes clear on constant stirring.

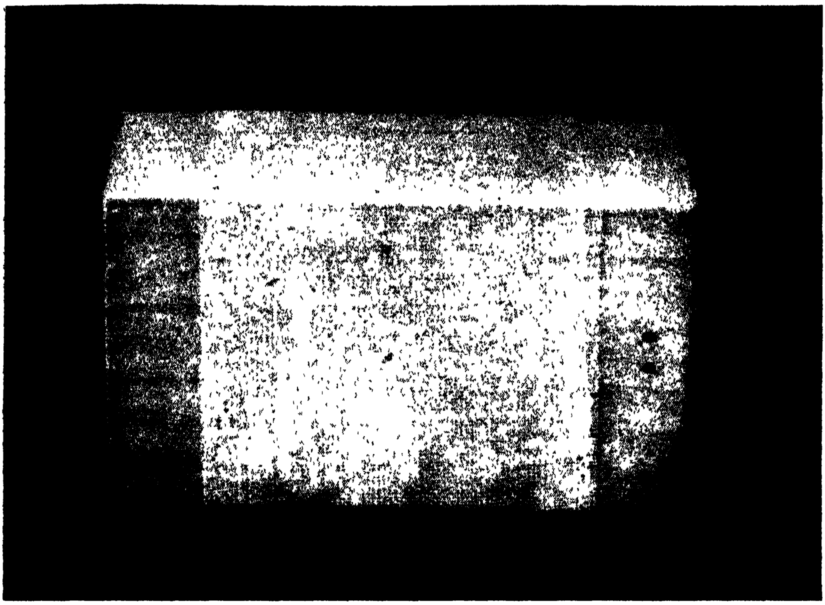
Technique.—Wood blocks were cut, with a fine-toothed saw, into the desired sizes, any with rough surfaces being resawn or discarded. Though most of the blocks in these tests were made with a hand-saw, a much quicker method, giving as good results, can be obtained by using a high-speed circular saw with fine teeth. This latter was used for some of the samples through the kindness of the owner of such a machine, and there were no discarded blocks among those sawn.

All blocks were then carefully examined under a binocular microscope to ensure that there were no eggs already present. The freshly-made flour-paste was painted thinly on the wood surfaces in situations on which it was hoped to have eggs deposited ; the muslin, in thicknesses varying from one to three layers, was wrapped lightly round these areas while the paste was still wet, and finally surplus paste was removed by pressing muslin closely to wood surfaces and squeezing it out to the sides, from which it was removed by a dry cloth. The completed block is shown in Fig. 1A. In the method finally preferred a cotton thread was wound round the blocks over the wet paste and then covered with a single layer of muslin (Fig. 1B).

In attempts to make *Anobium* disperse its eggs evenly over wood instead of grouping them all in one place, muslin bandages $\frac{1}{8}$ in. wide and short strands of cotton 2 in. to 3 in. long were used ; to secure "spot" ovipositions, small squares of muslin and cotton strands $\frac{1}{4}$ in. to $\frac{1}{2}$ in. long were pasted on ends and sides of blocks. In all cases, except for control blocks, there was muslin over the ends of blocks in addition to that on the sides.

Assembled blocks were placed in celluloid-sided cylinders $3\frac{1}{4}$ in. long and $3\frac{1}{4}$ in. in diameter and closed at each end by metal rings containing wire gauze disks. Blocks were placed upright in these cages, each of which held from three to four muslin-treated samples. A total of twenty-two cages was set up in the major experiments, involving sixteen replicates for kahikatea, forty-three for *P. radiata*, and five each for tawa and rimu. In ten of these cages a "control" block was placed with those bandaged ; this was a sample taken at random from those prepared for bandaging, but without any muslin, cotton, or paste.

Adult *Anobium* material was collected from kahikatea blocks in which it had been placed as larvæ in drill-holes, and from infested timber in houses and emergence cages. This material was then sexed under a 15x binocular microscope using the technique described by Kelsey, Spiller, and Denne (1945). Every female beetle collected was used in the experiments, so that the results form a true picture as to the value of this technique. Seven female and ten male beetles were placed in each of the cages, some of which were kept under the normal laboratory conditions of temperature and humidity operating in the air-conditioned building of the Plant Diseases Division, Auckland, and some under normal room conditions in an unheated Auckland dwelling.



[Photographs by V. G. Robinson.

FIG. 1A.—Muslin bandage alone.

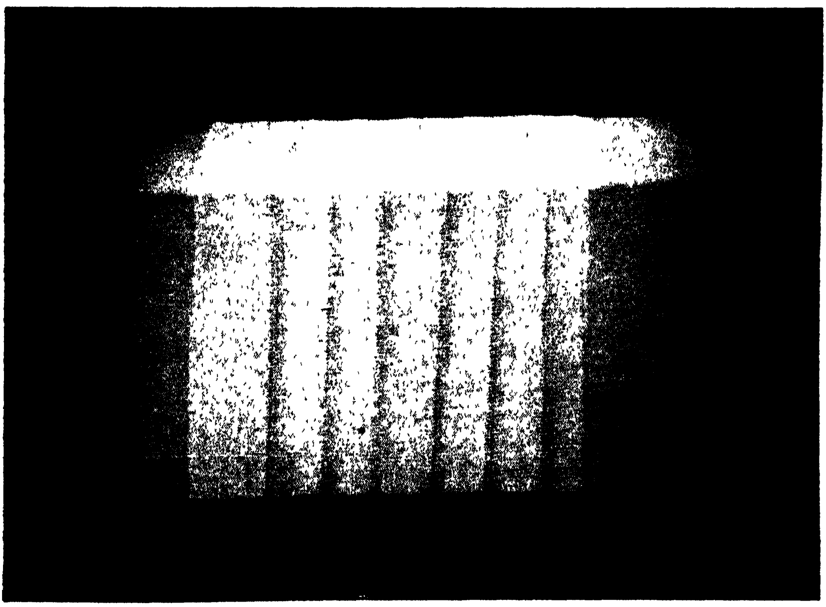


FIG. 1B.—Muslin bandage and thread.

EGG-LAYING

The lowest number of eggs laid per cage containing seven female beetles was 207 and the highest 459, giving averages per female of 29·6 and 65·6 respectively. The total number of eggs laid by 151 females in the major series of experiments was 6,441, so that the average number per female over the whole series was 42·7. These figures compare more than favourably with those given in the above paper by Kelsey *et al.* (*loc. cit.*), where the average per female for the several techniques, using every female beetle as in the present tests, was 23 ; the figure of 44·8 given in the previous paper as the highest average per female was obtained by selecting only those beetles that were found in copula, so that, though it is a very valuable technique, it is also a somewhat wasteful one.

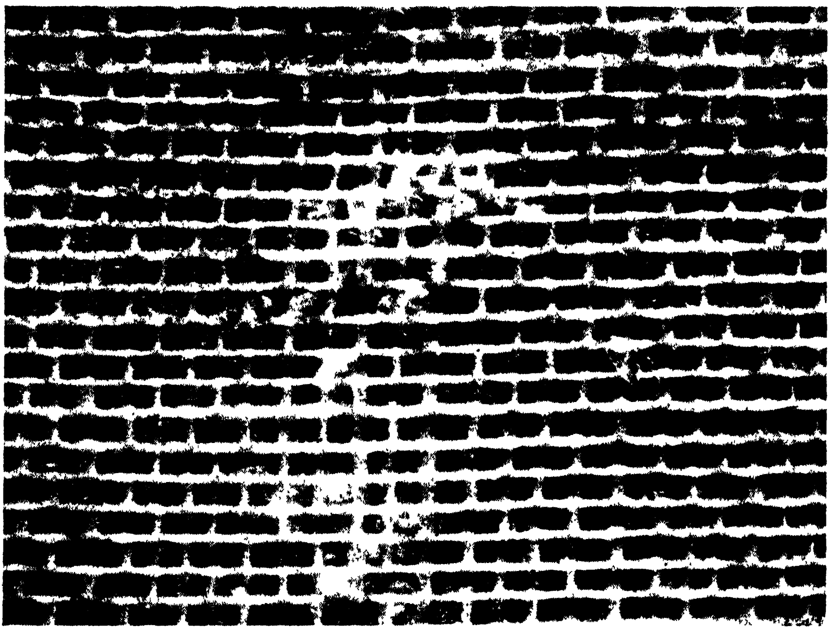


FIG. 2A —Eggs massed beneath muslin.

HATCHING

In regard to egg-hatching, the figures for the present investigations were slightly higher than those for the type 1 experiments mentioned in the previous paper and carried out under the air-conditioned-room temperatures at the Plant Diseases Division in prell cages. It therefore appears that the cage type used in these two series had very little bearing on the results ; it also confirms the hitherto unpublished opinion that there is normally for a large number of eggs a natural loss of from 4·0 to 7·5 per cent. in the number of eggs laid. Eggs involved in this 4·0 to 7·5 per cent. loss usually remained pellucid during development of normal eggs, and general dissections showed that the contents were watery, with no sign of embryonic development. This point must still await further experiments before being stated as more than an opinion, but it is significant that, under controlled so-called optimum temperature and humidity conditions, the hatching percentages for large batches of *Anobium* eggs did not exceed the figure of 93 per cent. (1945).

In the present investigations 93·55 per cent. of the eggs that were laid on muslin bandages hatched ; this is only 1·35 per cent. higher than for the previous two years' results under approximately similar conditions, and, taken in conjunction with these first figures, is important in indicating that it is possible, when working under the above room temperatures and humidities in Auckland, to obtain the practical maximum hatching for a large number of *Anobium punctatum* eggs.

TUNNELLING OF LARVÆ

The figure of 99·6 per cent. for initial tunnelling in of *Anobium* larvæ (as distinct from survival) in the muslin bandage technique was 0·2 per cent. lower than noted for the equivalent type 1 experiments in the previous work. "Tunnelling in" was recorded when newly hatched larvæ bored into the wood to a depth so that they were concealed by frass pellets of

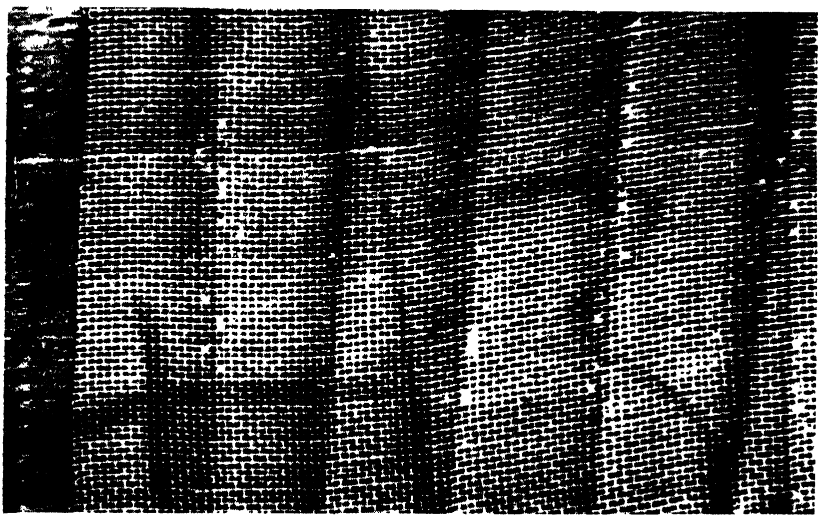


FIG. 2B.—Eggs dispersed along threads.

their own workings (Fig. 3). This percentage of 99·6 was based on the number of eggs that hatched and not on those actually laid ; on the latter basis the number of larvæ tunnelling in represented a figure of 93·15 per cent.

DISCUSSION

From the above figures it is apparent that, quite apart from other considerations, the bandage technique is worthy of further trial on the grounds that the numbers of eggs secured by using every female beetle collected are nearly twice those of the other methods. While this is probably largely due to more careful collection throughout a longer period each day, and to the utilization of beetles within two hours of collection, the muslin treatment is justified because it permits the recording of each egg laid. In earlier work, using roughened wood surfaces, it was found that the numbers of larvæ actually tunnelling in the blocks after six to eighteen months were greater than the recorded numbers of eggs laid on those blocks, and this in spite of the fact that the latter had been carefully inspected by means of a microscope to ensure that eggs or larvæ were not present already. The

only explanation is that during the experiments some eggs were so deeply wedged into crevices, &c., that they were overlooked when the counts were made.

There was no significant difference between the numbers of eggs laid on the blocks with muslin alone, and on those where cotton threads were placed beneath muslin, but the latter gave better results in that the eggs were dispersed over a wider area and not grouped in masses of 50 to 150 as on the former samples (Fig. 2A). Figure 2B shows that the thread-muslin method results in fairly uniform scattering of the eggs. The " dispersal " tests using the ⅛ in. wide strips of muslin over thread, and the " spot " experiments where muslin squares were pasted on blocks, were both satisfactory as no eggs were laid elsewhere than on treated areas. However, it

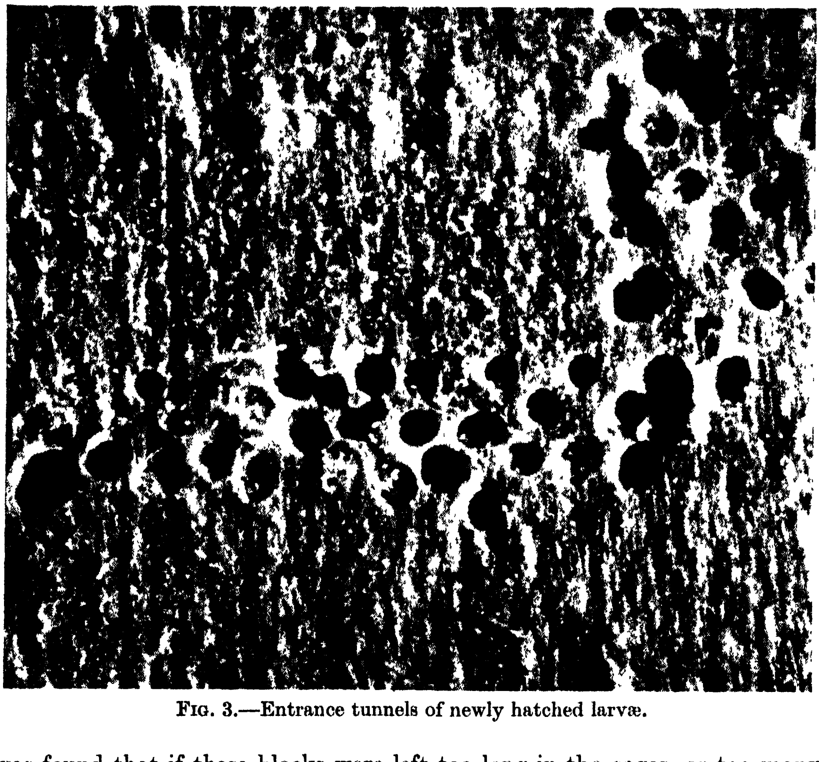


FIG. 3.—Entrance tunnels of newly hatched larvæ.

was found that if these blocks were left too long in the cages, or too many females were present in proportion to the available oviposition areas, the eggs were deposited in masses often three or four eggs deep, so that accurate counting was impossible. As the same dispersal can be secured by the wide muslin bandage and thread technique there is no reason for adopting the former treatment, which involves rather more time for preparation, except perhaps for carrying out laboratory experiments to elucidate certain finer points. In the general method, eggs were never found in more than one layer, though this would depend again on the ratio of oviposition area to the number of *Anobium* beetles in the cage.

Recommendations.—The use of more than a single thickness of muslin was not advisable as there was considerable difficulty in counting eggs where two or three layers were used. In future work it would speed up

the preparation of the blocks if a cellulose material could be used with a mesh approximately the size of the short diameter of *Anobium* eggs, as was the case with the muslin used in these tests, but with the thread as thick as the length of the eggs. This, when pasted on the blocks, would form small cells and would obviate the necessity of using the cotton strands which were used to raise the muslin the correct distance above the wood surface. It may be of interest also to use the cotton alone, as this was not attempted in the above experiments. Muslin dyed black, green, or any contrasting colour would facilitate the counting of the white eggs.

The final interest of the muslin bandage technique is shown by the fact that though sixty-nine muslin bandaged blocks were used in the main experiments, not a single egg was laid elsewhere than on the bandaged areas, though parts of each block were exposed (Fig. 1A). In cases where the thread was used beneath muslin, all eggs were laid along the threads (Fig. 2B). In the subsidiary test thirty-five blocks were used, and in these were included the ten control blocks with no muslin treatment. There was only one case where eggs, to the number of twenty-one, were laid on a control and not on bandaged blocks. The writer has no explanation for this, as the sample involved was as smooth in surface as the other blocks.

It is quite apparent that the use of the flour-paste, cotton threads, and muslin bandages had no effect on the maturation of *Anobium* eggs, on hatching of these, or on the initial tunnelling in of larvæ.

REFERENCE

KELSEY, J. M.; SPILLER, D.; DENNE, WINSOME (1945): Biology of *Anobium punctatum* (progress report). *N.Z. J. Sci. & Tech.*. *27 (Sec. B)*, 59–68.

ALKALOIDS OF THE LEGUMINOSÆ

PART XIV.*—ALKALOIDS OF *CYTISUS CANARIENSIS*, *C. STENOPETALUS*, AND ALLIED SPECIES

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Summary

Tops of *Cytisus canariensis*, *C. stenopetalus*, *C. hillebrandii*, and varieties and hybrids in this group contain up to 0·4 per cent. of alkaloid, consisting of methylcytisine with smaller amounts of cytisine. In some plants in the *C. stenopetalus* section there are, in addition, small amounts of anagyrine. Cytisine is the only alkaloid in seeds of the *C. canariensis* group and in seeds and tops of *Genista virgata* and *C. battandieri*. Cytisine and methylcytisine are in tops of *Baptisia australis*.

TOPS of several species of *Cytisus* and *Genista* were reported in Part XI(1) to contain cytisine-like bases, but only in a few cases was cytisine found to be the major alkaloid. The present section reports findings of a more detailed nature obtained from large-scale examinations of several species.

It is evident from Table I, and from the incomplete evidence in Part XI(1), that cytisine is the only alkaloid of tops and seeds of *Cytisus battandieri* (**stl** (February) 0·11, **s** 0·015) and *Genista virgata* (**stl** (February) 0·41, **s** 0·92)

* Continued from *N.Z. J. Sci. & Tech.* (1944) (*Sec. B*), *25*, 162.

and of seeds (1·0–1·5 per cent.) of the group comprising *C. canariensis*, *C. stenopetalus*, and allied species and hybrids. It is the major component of seeds of *Genista humifusa*. The alkaloid of tops of the *C. canariensis* group (up to 0·4 per cent.) was previously shown to contain cytisine in some cases, and some *C. stenopetalus* samples gave anagyrine (Part XI(1)). It is now found that only a small number of plants of the *C. stenopetalus* type produce anagyrine, and that this is a minor alkaloid. The major alkaloid of all samples of tops in the *C. canariensis-C. stenopetalus* section is methylcytisine, isolated previously from tops of *C. monspessulanus* (Parts XI, XV). The remainder of the crude base is cytisine. There is some variation in the relative proportions of the two bases in different plants of this section, and in no case was any sparteine or monspessulanine (Part XV) detected.

Some details of the source of specimens used is given, as many of these were distinct varieties whose identification was indefinite, though they approximated to *C. canariensis* or *C. stenopetalus*. *C. canariensis* Steud. was obtained from Spreydon Domain, Christchurch, a distinct variety of this from the Botanic Gardens, Christchurch, and a small-leaved, much-branched form from Cashmere, Christchurch, taken to be the var. *ramoissimus* Briq. (= *C. attleyanus* Hort.). A closely allied species is *C. hillebrantii* Briq. from Spreydon Domain. The larger-leaved forms were treated as *C. stenopetalus*, and probably included *C. maderensis* Masf. (*C. stenopetalus* is *C. maderensis* var. *magnifoliosus* Briq.), and hydrids with *C. canariensis*. The material at Karori, Wellington, was typical *C. stenopetalus*, together with some plants showing persistently small leaves, similar to *C. canariensis*. The material from Christchurch Botanic Gardens probably contained the hybrid form, *C. racemosus* Nich. Plants in the Wellington Botanic Gardens and in Bowen Street, Wellington, were distinct, having shorter racemes of flowers, and these forms persistently gave traces of anagyrine. Individual shrubs, apparently typical *C. stenopetalus*, found in the Botanic Gardens, Wellington, and at Weir House, Wellington, also gave some anagyrine.

An alkaloid study of the members of this group as they occur in the Canary Islands would be of considerable interest to taxonomy, as numerous allied species and varieties have been described. Two allied species have been investigated. *C. linifolius* gave only anagyrine (about 1·0 per cent.) in tops (Part X(2)), and *C. monspessulanus* of southern Europe gave in tops about 0·8 per cent. of base consisting of methylcytisine, cytisine, and monspessulanine (Part XV). Cytisine is the only alkaloid of seeds of these two species and of those investigated in this paper.

Tops of *Baptisia australis* (Podalyriæ) gave about 0·3 per cent. of base, free from anagyrine, and containing methylcytisine and cytisine. As reported in Part I(3), cytisine is stated to be present in tops, and was found in seeds.

EXPERIMENTAL

Isolation, Separation, and Identification of Bases

Isolation of crude alkaloid followed the method described in Part V(4), using continuous extraction in batches of up to 300 g. The alkaloid from all seeds, and the purified alkaloid from tops of *C. battandieri* and *G. virgata*, in each case crystallized readily like cytisine, gave the van der Moer reaction and the microchemical reactions of cytisine(4). The optical rotations in alcohol (Table I) agreed closely with that of cytisine, found$[\alpha]_D^{17}$ —113° (c = 0·466 in ethanol) and $[\alpha]_D^{17}$ —123° (c = 0·466 in water) for base of m.p. 154°. Recorded values for water are $[\alpha]_D^{25}$ —119·5°(5) and $[\alpha]_D$ —114·6°(6). In each case the picrate was prepared from aqueous solution

in high yield, decomposed at 270° (Table I), and showed no depression on admixture with authentic cytisine picrate, m.p. (dec.) 273°, recorded 273°(4), 277–279°(6, 7), and 302°(8).

TABLE I.—YIELDS AND PROPERTIES OF TOTAL BASES

Species and Locality.	Part	Weight (Grams)	Total Base *		Weight (Grams). Anagyrine	Picrate.	
			Weight (Grams).	$[\alpha]_D$ (Alcohol)		Weight (Grams)	m.p.
C. canariensis—							
Cashmere (February) ..	s	6·0	0·11	−103	..	0·17	269°
	stl	14·7	0·32	−94	Nil	0·15	235°
						0·21	135°
Christchurch B.G. (February)	s	8·2	0·10	−108	..	0·14	269°
	stl	173	0·13	−99	Nil	..	..
Spreydon (February) ..	stl	214	0·53	−121	Nil	0·63	255°
						0·19	211°
C. stenopetalus—							
Karori—							
Large leaves (May) .	s	120	1·37	−105	Nil	..	273°
	stl	1518	3·42	−145	Nil	..	..
	..	..	0·20	−161	..	0·36	178°
Small leaves (May) ..	stl	538	1·15	−142	Nil	1·79	216°
						0·13	105°
Mixed sample (November) ..	stlfl	900	0·91	−151	Nil	..	.
C. stenopetalus—							
Christchurch B.G. (February)	stl	124	0·19	119	Nil	0·29	170
						0·11	190°
Wellington B.G. (November)	stlfl	392	1·34	−123	0·06	..	..
Bowen Street (August) ..	stlfl	340	1·67	−123	0·13	..	..
C. hillebrantii (February) ..	stl	288	0·36	129	Nil	..	..
G. virgata (February) ..	s	11·4	0·10	−99	Nil	0·17	269°
	stl	122	0·48	99	Nil	0·65	266°
C. battandieri (February)	s	15·8	0·025	..	Nil	0·05	271°
	stl	405	0·51	100	Nil	..	272°
G. humifusa	sp	2·9	0·02	..	..	0·02	267°
Baptisia australis (February) ..	stl	123	0·33	−120	Nil	..	..

* Purified from tops, not from seeds.

The total base from each sample of tops was first purified by dissolving in dilute hydrochloric acid, filtering off chlorophyll-like material, and clarifying with norite. The concentrated solution was treated with excess perchloric acid and sodium acetate, with sometimes further concentration. In this way the major part of any anagyrine was precipitated as perchlorate (*cf.* Part X(2)), and on recrystallization was identified by mixed m.p. data with anagyrine perchlorate m.p. (dec.) 296° (Part X). The solution was then made strongly alkaline and extracted with chloroform. The recovered base generally crystallized in part. The optical rotations showed the presence of bases of higher rotation than cytisine (Tables I and II). In many cases the picrates were prepared from alcohol solution. Some showed no further depression on admixture with cytisine picrate, others with methylcytisine picrate. Recrystallizations from alcohol gave least soluble fractions of m.p. close to that of cytisine picrate and showed no depression on admixture, but no clear-cut separation of components could be obtained through the picrates. Picrate fractions of each sample were combined and converted to hydrochlorides by suspension in dilute hydrochloric acid and extraction of the picric acid with ether. The solutions from each sample, or in most cases solutions of purified base which had not been converted to picrates, were treated with benzenesulphonylchloride following Ing(9), and benzene-

sulphonylcytisine filtered off. The weight of cytisine was calculated (Table II). Each precipitate was recrystallized from hot ethanol, giving a high yield of shining prisms, m.p. 254°-261°, showing no depression on admixture with benzenesulphonylcytisine m.p. 261°; recorded diamond-shaped prisms, m.p. 263–4°(9).

Bases were recovered by extraction of the alkaline filtrate with chloroform as discoloured partly crystalline materials, of optical rotations in alcohol (Table II), those expected of slightly impure methylcytisine. In each case the picrate was obtained in high yield from alcoholic solution and of m.p. close to that of methylcytisine (Table II). These picrates showed no further depressions on admixture with methylcytisine picrate, m.p. 226°, recorded 223°-230°(6, 7, 10, 11, 12), and on recrystallization approached 227°. In some cases portions of this base were recrystallized from benzene-petroleum ether in colourless needles, m.p. 134°–138°, not depressing authentic methylcytisine, m.p. 137°, recorded 134° 138°(6–13). One sample gave $[\alpha]_D^{15}$ —218° (c = 1·334 in water), $[\alpha]_D^{15}$ —178° (c = 1·334 in ethanol), and another $[\alpha]_D^{17}$ —224° (c = 1·237 in water). Recorded for water $[\alpha]_D$ —217°(8), $[\alpha]_D$ —221·6° (c = 1·128)(10, 11), and for ethanol Orechov(13) found a variation with concentration $[\alpha]_D$ —190° (c = 1·0), $[\alpha]_D$ —170° (c = 5) and $[\alpha]_D$ —154° (c = 30). Appreciable amounts of monspessulanine in these fractions were excluded by the high optical rotations and high yields of picrates from the crude base, and particularly from the methylcytisine fractions. Extraction of some methylcytisine fractions in water by ether gave no monspessulanine (*cf.* Part XV).

TABLE II.—CYTISINE AND METHYLCYTISINE YIELDS FROM CRUDE BASES OF TOPS

Species.	Crude Base.		Cytisine Weight (Grams)†.	Methylcytisine.			
	Weight (Grams).	Rotation $[\alpha]_D$*.		Weight (Grams).	$[\alpha]_D$†.	Picrate.	
						Weight (Grams).	m.p.
C. canariensis—							
Cashmere	0·16	−106°	0·03	0·08	−176°	0·17	203°
Christchurch B.G. ..	0·13	−98°	0·04	0·06	−165°	0·07	211°
Spreydon	0·39	−129°	0·13	0·14	−163°	0·21	223°
C. stenopetalus—							
Karori—							
Large leaves ..	2·04	−155°	0·25	1·49	−159°	..	221°
Small leaves ..	1·00	−143°	0·22	0·57	−169°	1·12	219°
Christchurch B.G. ..	0·19	−129°	0·05	0·08	−175°	0·17	215°
Wellington B.G. ..	1·26	−128°	0·59	0·61	−159°	1·29	222°
Bowen Street ..	1·67	−123°	0·58	0·84	−158°	..	..
	..	..	..	0·09	..	0·21	216°
C. hillebrantii	0·35	−125°	0·09	0·19	−168°	0·28	219°
Baptisia australis ..	0·25	−135°	0·06	0·16	−171°	0·26	214°

* Optical rotations in alcohol at c = 0·7–1·9. † Calculated from weight of crude benzenesulphonylcytisine.

Microchemical Slide Reactions of Methylcytisine

Neutral or slightly acid solutions were used. Potassium bismuth iodide gave a heavy amorphous precipitate, potassium mercuric iodide little in aqueous solutions of the base, much amorphous material in acid solution forming slowly some tiny spheroids. This reaction is quite distinct from that of cytisine (Part V). Potassium cadmium iodide gave little in the

aqueous solution of the base, but a heavy amorphous precipitate in acid solutions, crystallizing with difficulty and sometimes forming huge spheroids of fine needles. Potassium tri-iodide gave large black needle clusters developing to rods. Gold bromide formed fern-like material and characteristic blades with transverse outgrowths, gold chloride curved needle clusters developing to thin blades and plates with transverse outgrowths. Picric acid gave large needles and prisms like those from cytisine, and mercuric chloride only in very concentrated solutions, large spheroids of fine needles forming slowly around the edges. No bromosalts(14) were formed with cadmium, mercury, bismuth, lead, or antimony, even in very concentrated solutions.

REFERENCES

(1) WHITE, E. P. (1944): *N.Z. J. Sci. & Tech.*, *25* (*Sec. B*), 148.
(2) ——— (1944): *Ibid.*, 143.
(3) ——— (1943): *Ibid.*, 95.
(4) ——— (1943): *Ibid.*, 106.
(5) PARTHEIL, A. (1892): *Arch. Pharm.*, *230*, 448.
(6) BRIGGS, L. H., and RUSSELL, W. E. (1942): *J. Chem. Soc.*, 507.
(7) BRIGGS, L. H., and RICKETTS, J. (1937): *Ibid.*, 1797.
(8) MANSKE, R. H. F., and MARION, L. (1943): *Can. J. Res.*, *21B*, 144.
(9) ING, H. R. (1935): *J. Chem. Soc.*, 1053.
(10) POWER, F. B., and SALWAY, A. H. (1913): *Ibid.*, *103*, 124.
(11) BRIGGS, L. H., and TAYLOR, W. S. (1938): *Ibid.*, 1207.
(12) NORKINA, S. S., NARKUZIEV, T.; and ORECHOV, A. P. (1937): *J. Gen. Chem. (U.S.S.R.)*, *7*, 906. (*Chem. Abs.*, *31*, 6412.)
(13) ORECHOV, A. P.; NORKINA, S. S.; and GUREWITSCH, H. (1934): *Ber.*, *67*, 1394.
(14) WHITE, E. P. (1941): *Ind. Eng. Chem.* (*Anal. Ed.*), *13*, 509.

PART XV.—ALKALOIDS OF *CYTISUS MONSPESSULANUS* L.

Summary

Tops of *C. monspessulanus* gave up to 0·9 per cent. of alkaloid, consisting of 50–60 per cent. methylcytisine and 15 per cent. cytisine. The remainder was a hitherto-unreported, feebly basic lupanine-like alkaloid, $C_{15}H_{22}ON_2$, m.p. 101°. This has been named monspessulanine. Its methiodide, m.p. 247°, hydrochloride (very deliquescent), and perchlorate, m.p. 215°, were the only salts that could be prepared. It is allied to the lupanine group of bases, and contains an inert keto group and one double bond. Catalytic reduction gave a base $C_{15}H_{24}ON_2$, m.p. 99°, perchlorate, m.p. 224°, not identified with any known base of this formula. Monspessulanine is an isomer of aphyllidine.

IN Part XI(1) it was shown that the only alkaloid of seeds of this species is cytisine, while in tops 0·6–0·7 per cent. of alkaloid was found. This was a mixture from which about a quarter of the alkaloid was obtained as impure methylcytisine picrate. Present studies showed that about a third of the total alkaloid can be obtained as methylcytisine picrate from alcohol, but the bases in the mother-liquor proved difficult to separate. The absence of anagyrine has been further established.

In large-scale examination of the total alkaloid, cytisine was first removed as the benzenesulphonyl derivative (*cf.* Part XIV), and constituted about 15 per cent. of the total base. The base recovered from the mother-liquor was treated with water and extracted with ether, when a comparatively pure fraction was removed, constituting about 30 per cent. of the total base. This is distinct from previously reported bases, and is named monspessulanine. The aqueous solution was then made strongly alkaline,

and on extraction gave crude methylcytisine, which was identified in detail. It constitutes about 50 per cent. of the total base. This separation depends on the different solubilities of the two bases in water and ether.

The large-scale studies were done on typical samples of the naturalized plant. Two specimens of horticultural origin approximated to *C. monspessulanus*, but showed certain differences, one resembling *C. canariensis* in leaf characteristics. Both gave alkaloid indistinguishable from that of typical material. The close similarity of this species to the *C. canariensis*-*C. stenopetalus* group was noted in Part XIV. Tops of all these species gave methylcytisine as the major alkaloid, with smaller amounts of cytisine. *C. monspessulanus* differs from the others in having a higher alkaloid content and the extra base monspessulanine.

Monspessulanine, $C_{15}H_{22}ON_2$, was obtained with difficulty as crystals by addition of water to an acetone solution, it remaining as an oil if slightly impure. The base had a m.p. 101°, and $[\alpha]_D$ −117° (alcohol). Unlike the cytisine bases, it gave no van der Moer reaction. It was sparingly soluble in cold water, much less soluble in hot water, in this respect resembling lupanine and allied bases. The base was faintly alkaline to litmus and salts were dissociated and difficult to prepare. The monohydrochloride, m.p. 244°, was extremely deliquescent. A monomethiodide, m.p. 249°, was obtained in small yield only by a sealed-tube technique, the base being stable to refluxing with methyl iodide in solvents. Analysis of two preparations showed that this methiodide contained, in addition to B,CH_3I, the elements of $\frac{1}{2}$ H_2O. The perchlorate from sodium acetate and perchloric acid solutions separated in rods, m.p. 208°, in low yields from pure concentrated solutions.

The base contained no group capable of acetylation, no reactive keto, amine-oxide, methoxy, or alkimide group, and was unaltered by nitrous acid. Of the two nitrogen atoms one was inert, and the other only feebly basic. The oxygen is probably present as an inert keto group, which accounts for lack of basicity of at least one nitrogen in this series of bases.

The base had powerful reducing properties, instantly reducing permanganate, and the gold chloride was completely reduced to gold on attempted recrystallization from hot water. Catalytic hydrogenation gave dihydromonspessulanine, $C_{15}H_{24}ON_2$, m.p. 97°, $[\alpha]_D$ + 10–13° (alcohol), and a sparingly soluble perchlorate, m.p. 222°. The reduced base contained only tertiary nitrogen. The perchlorate showed depression on admixture with that of *dl*-lupanine, m.p. 213°. The microchemical reactions showed a similarity to those of sparteine and retamine.

The only reported base, $C_{15}H_{22}ON_2$, known to be allied to the "papilionaceous" bases is aphyllidine, m.p. 112–3°, $[\alpha]_D$ + 6·5° (methyl alcohol), methiodide m.p. 223–5°, hydrochloride m.p. 235–7°, perchlorate m.p. 210–212°, obtained by Orechov(2, 3) from *Anabasis aphylla* (Chenopodiaceæ). Aphyllidine is reduced catalytically to aphylline, $C_{15}H_{24}ON_2$, an isomer of lupanine, which does not form an insoluble perchlorate. Monspessulanine and the dihydro base show considerable similarity to these bases and to lupanine, and the other numerous isomers of $C_{15}H_{24}ON_2$, but monspessulanine appears to represent yet another structural isomer of this series. In respect to unsaturation, it represents a state between anagyrine, $C_{15}H_{20}ON_2$, and lupanine, $C_{15}H_{24}ON_2$.

EXPERIMENTAL

Isolation and Separation of Fractions

In some early experiments, 880 g. of still (November) gave 5·37 g. of crude base, $[\alpha]_D$ −78° (alcohol). This gave from alcohol 3·79 g. of picrate,

m.p. 210° or higher, not showing depression with methylcytisine picrate (see Part XI). Similarly, 365 g. of **stlfl** gave 1·68 g. of base, $[\alpha]_D$ −78° (alcohol), and 1·24 g. of picrate, m.p. 212°, and in another case 515 g. of **stlfl** gave 3·89 g. of base, yielding 2·48 g. of picrate, m.p. 214°. The base recovered from the mother-liquors was a thick syrup, which was further purified by extraction with ether. The syrup had a slight negative rotation and n_D^{16} = 1·5521, indicating unsaturation. It formed a very deliquescent hydrochloride, and no crystalline derivatives could be obtained. 144 g. of seeds gave 1·59 g. of crystalline base, $[\alpha]_D$ −109° (alcohol), giving reactions of cytisine, and a high yield of cytisine picrate, m.p. 273°.

3·99 kg. of **stlfl** (February and May) were continuously extracted and crude base obtained as in Parts V(4) and XIV. 32·8 g. of crude base obtained was dissolved in acid and 3·97 g. of tarry chlorophyll-like material removed. The solution was further purified with norite, excess sodium hydroxide was added, and the solution was shaken with benzenesulphonylchloride. The brown precipitate weighed 5 g and was designated " fraction A."

The strongly alkaline mother-liquor was extracted with chloroform; 22·4 g. of varnish-like base were obtained, $[\alpha]_D$ −85° (alcohol). Extraction with ether or petrol-ether removed low-rotation fractions preferentially, but no sharp separation was obtained. Fractions were recombined, and distilled at ca. 0·1 mm. in a small quick-fit apparatus without fractionating column. 13·3 g. of base, $[\alpha]_D$ −40°, distilled at 184–192°, and a further 3·9 g., $[\alpha]_D$ −60°, from 200–204°. The residue in the flask was extracted with acetone, when 1·6 g. of dark material was removed. This was designated " fraction D."

Distillates were recombined (16·9 g.) and treated with water, when some colourless crystalline material remained undissolved. The suspension was extracted with six lots of ether. The residue after removal of solvent weighed 6·85 g. and had $[\alpha]_D$ −115° (c = 1·32 in alcohol). It crystallized partly on standing and was designated " fraction B." The aqueous phase was made strongly alkaline and extracted with chloroform. The residue, 9·06 g., $[\alpha]_D$ −160° (c = 1·98 in alcohol), crystallized and was designated " fraction C."

321 g. of **stl** (June) of a slightly different form (from Weir House) gave 3·2 g. of purified base, $[\alpha]_D$ −102° (alcohol). From this was obtained 0·45 g. of benzenesulphonylcytisine, m.p. 255°. The recovered base weighed 2·62 g., of which 0·39 g., $[\alpha]_D$ −80°, was extracted by ether from an aqueous solution partially neutralized with acid, and this base became semi-crystalline on standing. Further extraction with chloroform gave 1·55 g. of crystalline base, $[\alpha]_D$ 160°. 94 g. of **stl** (September) from an alleged *Genista* species believed to be *C. monspessulanus* gave 0·69 g. of base, $[\alpha]_D$ −67° (alcohol). This gave no anagyrine perchlorate, 0·22 g. of benzenesulphonylcytisine, and a recovered base 0·36 g., $[\alpha]_D$ −78° (alcohol). The ether-extractable fraction weighed 0·12 g., $[\alpha]_D$ +78° (alcohol), and the chloroform extract 0·17 g., $[\alpha]_D$ −159° (alcohol).

Identification of Fractions

" Fraction A " was recrystallized from hot ethanol. 4·1 g. of colourless shining prisms separated, m.p. 257°. These showed no depression with authentic benzenesulphonylcytisine of m.p. 261° (see Part XIV).

" Fraction D " was dissolved in hot alcohol, and on standing some crystals separated. The dark base left on drying the alcohol was insoluble in water, sparingly soluble in ether, evidently containing little monspessulanine or methylcytisine. It was dissolved in dilute hydrochloric acid, when a few more crystals separated on standing. The dark hydrochloride

left on drying amounted to 1·03 g. It was deliquescent and nothing crystalline could be prepared from it. The crystalline fractions, 0·21 g., melted at 255° and were benzenesulphonylcytisine.

"Fraction C" was recrystallized from benzene and petrol-ether. First some discoloured sticky material separated, then the major fraction, 5·9 g. of colourless needles, m.p. 131–3°. Further concentration gave 2·2 g. of slightly discoloured crystals, m.p. 124°. These minor fractions were purified with difficulty and were impure forms of the main fraction. A portion of base further purified gave needles, m.p. 137°, soluble in water and giving the van der Moer reaction, $[\alpha]_D$ −213° (c = 1·153 in water), $[\alpha]_D$ −179° (c = 1·028 in alcohol). It gave $CH_3(N)$ = 7·7, calculated for $C_{11}H_{13}ON_2,CH_3$ is 7·3. The picrate, m.p. 226°, did not depress authentic methylcytisine picrate of the same m.p. For recorded data on methylcytisine see Part XIV.

"*Fraction B.*"—A 6-gram portion was used. Attempts to crystallize from numerous solvents gave only discoloured oils. The fraction was dissolved in acetone, water added until a cloudiness appeared, then the acetone was blown off slowly with a fan. A little tarry material separating at first was removed mechanically. The oily precipitate gave crystals after refrigeration at intervals, and removal of most of the acetone. 2·6 g. of colourless plates were obtained, m.p. 100°, $[\alpha]_D$ +117° (c = 2·62 in alcohol). Further concentration gave only oily material. The solution was extracted with ether and the base again obtained by the acetone-water procedure, when a further 0·99 g. of colourless plates, m.p. 95°, were obtained. The mother-liquors gave only discoloured oils, so the solution was again extracted with ether, giving 1·06 g. of semi-crystalline discoloured base, $[\alpha]_D$ +85° (alcohol), which was monspessulanine with a little non-alkaloidal material.

Investigation of Monspessulanine

Monspessulanine Base.—A portion of the m.p. 100° base was further recrystallized from acetone-water, giving rods, m.p. 101°, $[\alpha]_D$ +117° (c = 2·01 in alcohol). Analysis gave—

——	Found.	Calculated for $C_{15}H_{22}ON_2$.
C	73·3, 73·4	73·17
H	9·13, 9·02	8·94
N	11·2, 11·3, 11·1	11·38

Methoxy and $CH_3(N)$ determinations were negative. Molecular weight (Rast) = 224, calculated for $C_{15}H_{22}ON_2$ is 246. The base had a characteristic odour resembling that of lupinine. It was sparingly soluble in water, and much less soluble in hot water, readily soluble in ether and in most organic solvents, including petrol-ether. The aqueous solution gave a brown precipitate with ferric chloride, but no van der Moer reaction. The aqueous solution was faintly alkaline to litmus and phenolphthalein, alkaline to methyl red and methyl orange. 71·7 mg. of base in water required 2·01 ml. of 0·1N hydrochloric acid for neutralization to methyl red, indicating a hydrochloride, acid to this indicator. The base was not steam-volatile, and was unaltered by long refluxing with acetic anhydride or by the action of sodium nitrate and hydrochloric acid. It gave no ketone reactions, and was unaltered by the continuous action of sulphur dioxide. Electrolytic reduction over mercury at 30 volts and 1·5 amp. was without effect.

Monspessulanine Hydrochloride.—The residue from titration of the base was dried and washed with acetone to remove free base. The colourless material left melted at 244° and was extremely deliquescent. It gave Cl = 12·7, 12·8, theory for $C_{15}H_{22}ON_2,HCl$ is Cl = 12·6. The hydrochloride prepared from alcoholic hydrochloric acid was also very deliquescent and could not be purified.

Monspessulanine Perchlorate.—A concentrated solution of the hydrochloride with excess sodium acetate and perchloric acid deposited a low yield of rods, m.p. 198°. Recrystallization from acetone-ethyl acetate formed rods, m.p. 214–5°. Analysis gave*—

—	Found.	Calculated for $B,HClO_4$.
C	51·42	51·95
H	6·83	6·64

* The material was reported difficult to burn.

Monspessulanine Methiodide.—The base in acetone, benzene, ether, or without solvent on refluxing with methyl iodide for several hours was recovered unchanged. In one case a trace of material, m.p. 214°, separated. 317 mg. of base and excess methyl iodide were heated in a sealed tube on a water-bath for six hours. Crystals separated slowly, and the whole was dried. Recrystallization from acetone-ether formed 108 mg. of prisms, m.p. 247°, readily soluble in water. Analysis of separate preparations gave—

—	Found.	Calculated for $C_{15}H_{22}ON_2$, $CH_3I, \frac{1}{2}H_2O$.
C	47·70, 48·35	48·36
H	6·78, 6·21	6·55
N	7·02, 6·97	7·05
I	34·0, 33·3, 33·4	32·0
CH_3(N)	3·8, 4·2	3·98

From the mother-liquor, 180 mg. of unaltered base were recovered. The aqueous solution on making alkaline with sodium hydroxide and extracting with chloroform gave only a trace of base.

Monspessulanine Aurichloride.—A slightly acid solution with excess gold chloride formed an orange precipitate soon changing to fern-like clusters, m.p. 120–135°. Attempts to recrystallize this salt resulted in oily material from alcohol, and from dilute acid solution reduction to gold took place.

Reduction of Monspessulanine.—To 360 mg. of base was added 134 mg. of Adams catalyst, 70 ml. of water, and 5 ml. of concentrated hydrochloric acid. This solution absorbed approximately one molecular equivalent of hydrogen. The solution was made alkaline and extracted with chloroform giving 333 mg. of base, m.p. 88°, $[\alpha]_D$ +10° (alcohol). The base was purified by extraction with petrol-ether, in which it was readily soluble, giving on evaporation a crystalline mass, m.p. 98°. Monspessulanine was also hydrogenated at 85°, giving the same base, m.p. 90–95°, $[\alpha]_D$ +9° (alcohol).

Dihydromonspessulanine Base.—A mixed sample was further purified from petrol-ether to crystals, m.p. 98°, $[\alpha]_D$ +13° (c = 0·719 in alcohol). The mixed m.p. with monspessulanine base was 90–94°. Analysis gave—

—	Found.	Calculated for $C_{15}H_{24}ON_2$.
C	72·0	72·58
H	9·56	9·67
N	11·0	11·29

The base was stable to nitrite and dilute acid.

Dihydromonspessulanine Perchlorate.—A portion of base was dissolved in dilute hydrochloric acid. Perchloric acid and excess sodium acetate were added. Large plates separated in fair yield, m.p. 225–7° (dec.), with darkening from 214°. Recrystallization from acetone and ethyl acetate gave 19 mg. of plates, m.p. 223° (dec.). Admixture with *dl*-lupanine perchlorate, m.p. 213°, ex *Podalyria buxifolia*, gave a value 197–200°, and with monspessulanine perchlorate, m.p. 214–5°, a value 206–7°. Analysis gave—

—	Found.	Calculated for $C_{15}H_{24}ON_2HClO_4$.
C	51·97	51·64
H	7·23	7·22

Microchemical Slide Reactions of Monspessulanine.—The saturated aqueous solution and a more concentrated acid solution were used. There was obvious alliance to sparteine and retamine in many reactions, and precipitates of considerable insolubility were formed with most reagents. Potassium bismuth iodide formed an amorphous precipitate not crystallizing, potassium tri-iodide an oil which did not crystallize, and picric acid a faint amorphous precipitate which in rare cases formed a few spheroids. The heavy precipitate with potassium mercuric iodide formed clusters of fine rods and needles rapidly. Potassium cadmium iodide gave a more soluble precipitate crystallizing rapidly to characteristic blades and plates with transverse outgrowths, reminiscent of the sparteine iodocadmium salt. Mercuric chloride gave a slight amorphous precipitate which soon gave many prisms in characteristic clusters often joined in a thread-like fashion. Gold chloride formed a heavy precipitate, usually crystallizing in a short time to clusters of blades and plates with transverse outgrowths. The precipitate with gold bromide formed peculiar spheroids and moss-like clusters appearing red under the microscope. A saturated aqueous solution gave a slight amorphous precipitate with potassium mercuric bromide, none with the other bromo salts. Details of procedure for these tests are given elsewhere(5, 6). The more concentrated acid solution gave with potassium mercuric bromide a slight precipitate rather like that with mercuric chloride. With potassium cadmium bromide there was a slight precipitate in very concentrated solution, with the bismuth, lead, and antimony salts no precipitate. No precipitates were obtained with potassium ferricyanide, platinum chloride, or potassium chromate.

The dihydro-base gave slide reactions very similar to those of monspessulanine with potassium bismuth, mercuric, and cadmium iodides, gold bromide, picric acid, and the bromo salts. Some were reminiscent of those of sparteine. There was a persistent distinction from monspessulanine, in

that the gold chloride formed rods crossed at an oblique angle, and mercuric chloride gave a slight amorphous precipitate which would not crystallize. The potassium tri-iodide precipitate was an oil, forming some characteristic clusters of fern-like threads and needles.

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REFERENCES

(1) WHITE, E. P. (1944): *N.Z. J. Sci. & Tech.*, *25* (*Sec. B*), 148, 151.
(2) ORECHOV, A. P., and NORKINA, S. S. (1934): *Ber.*, *67*, 1845.
(3) ORECHOV, A. P. (1937): *J. Gen. Chem. (U.S.S.R.)*, *7*, 2048. (1938): *Brit. Chem. Abs.*, *A*, *ii*, 74.
(4) WHITE, E. P. (1943): *N.Z. J. Sci. & Tech.*, *25* (*Sec. B*), 108.
(5) ——— (1941): *J. Am. Pharm. Assoc.*, *30*, No. 6, 156.
(6) ——— (1941): *Ind. Eng. Chem. (Anal. Ed.)*, *13*, 509.

REVIEW

MAPS OF AVERAGE RAINFALL IN NEW ZEALAND

Maps of Average Rainfall in New Zealand, by C. J. Seelye, M.Sc., Ph.D., Air Department, Meteorological Office, Wellington.

This publication contains maps of New Zealand showing (i) average annual rainfall; (ii) average monthly rainfall; (iii) average number of rain-days per annum.

The material for these was prepared originally for the projected Centennial Atlas, the publication of which has been suspended meantime, and is presented here in a less elaborate form.

All rainfall records up to the end of 1937 and available in the Meteorological Office, Wellington, were used, and the maps represent the average over the thirty-year period, 1901–30. For most purposes the actual epoch is immaterial and the results may be considered the "long period average." The previous annual rainfall map which was published by the late Dr. E. Kidson in 1930 had for its standard epoch the thirty-five years, 1891–1925. The increased information accumulated since then has not led to any drastic change in the annual isohyets, although numerous variations in detail will be at once apparent.

It may be remarked that comparisons among the records for the purpose of reduction of the available average to that of the basic period seem least satisfactory in the North Auckland and Gisborne districts, where the variations within short distances have at times been very erratic.

Average rainfall maps for the odd months were included in the article by E. Kidson on "Climatology of New Zealand," published in Koppen and Geiger's "Handbuch der Klimatologie," Band IV, Teil S (Berlin, 1932). The present set of twelve-monthly maps is drawn in rather greater detail. To utilize short records to the best advantage, the standard method of preparing the monthly maps is as follows and may appear at first sight unduly complex. Available lengthy records were averaged over their full period and the monthly averages were expressed as a percentage of the annual average. These percentages were plotted on separate maps for each of the twelve months and lines of equal percentages (isomers) were drawn. The greatest weight was given to the longest records, and to draw the isomeric patterns a certain amount of smoothing was involved. The percentage rainfalls were then re-estimated from the final isomers on the maps at all places for which there was sufficient information to derive a direct or estimated value of the average annual rainfall for 1901-30, and percentages thus found were applied to these annual values. The monthly totals so obtained were the basis of the maps shown here, there being 531 sets of figures for the North Island and 417 for the South. The process outlined eliminates largely the very appreciable effects of abnormal months upon the averages obtained directly from records covering short or moderate periods only.

For the rain-day map the precise period was not critical, and direct averages were used and supplemented by estimates when the record was no more than a few years in length.

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MAGNETIC IRONSAND-ORES WEST OF WANGANUI

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Summary

This paper presents the results of a reconnaissance survey of the ironsand deposits in Westmere and Nukumaru Survey Districts, west of Wanganui. Extensive Pleistocene deposits underlying good farming land are unlikely to be utilized as iron-ore; they are estimated to contain from 130,000,000 tons to 250,000,000 tons of titanomagnetite. Recent beach and dune sands have been mapped in more detail, and the quantity of titanomagnetite in them estimated at about 22,000,000 tons.

The sands are low-grade iron-ores, the mean content of titanomagnetite being under 20 per cent. Estimation of the quantities of titanomagnetite has been based on magnetic separations, followed by grain-count analyses of the magnetic fractions, of thirty-seven sand samples by Dr. C. O. Hutton, Petrologist, N.Z. Geological Survey. Quantitative analyses by Mr. J. J. S. Cornes, Dominion Laboratory, for acid-soluble iron, titanium, and vanadium have shown that the magnetic fractions of Wanganui and Patea sands are closely similar.

INTRODUCTION

THE possible use of New Zealand ironsands as a source of iron, titanium, and vanadium has recently been reviewed by Brian Mason (1945). The results of detailed surveys of two ironsand areas in Taranaki Patea and Fitzroy --have been published by C. O. Hutton (1940, 1945). Full references to previous work on New Zealand ironsands are to be found in the three papers cited.

The present report is the result of a reconnaissance survey of extensive low-grade ironsand deposits in Westmere and Nukumaru Survey Districts undertaken by the writer (with the assistance of Mr. A. C. Beck, N.Z. Geological Survey) in the early months of 1945. The work was done as part of the regional geological mapping of the Wanganui Subdivision, as yet incomplete.

The ironsand-ores consist of beach and dune sand deposits of Recent age, together with similar deposits of Pleistocene age. The Pleistocene deposits form the coverhead of two marked coastal benches (which have been named the Brunswick and Rapanui Terraces) and underlie first-grade agricultural land. For this reason it is unlikely that they will be worked, and detailed quantities have not been assessed.

The titanomagnetite sands of Taranaki and West Wellington are believed to be derived from the effusive products of the augite-andesite cone, Mount Egmont. No evidence has been seen that Egmont was active in latest Pliocene (Castlecliffian) times, and there is evidence that derivatives from Egmont first appeared in the Wanganui area after the earliest beds covering the Brunswick Terrace were deposited.

CLASSIFICATION OF IRONSAND DEPOSITS

The sediments overlying the upper (Brunswick) Marine Terrace and their correlatives have been named the Brunswick Formation, and those over the lower (Rapanui) Terrace the Rapanui Formation.

(1) Pleistocene ores of the Brunswick Formation (? Mid-Pleistocene) :—
- (*a*) Pebbly beach sands.
- (*b*) Magnetite-rich beach sands.
- (*c*) Dune sands.

(2) Pleistocene ores of the Rapanui Formation (Late Pleistocene) :—
- (*a*) Beach sands.
- (*b*) Rapanui dune sands.

(3) Recent ironsand deposits :—
- (*a*) Beach sands.
- (*b*) Dune sands—
  - (i) Nukumaru Dune Complex (Fig. 2).
  - (ii) Okehu Dune Complex (Fig. 3).
  - (iii) Kai Iwi Dune Complex (Fig. 3).
  - (iv) Westmere Dune Complex (Fig. 4).

PLEISTOCENE IRONSAND DEPOSITS

Pleistocene stratigraphy will not be discussed in detail, but it may be noted that the two formations recognized are roughly equivalent to the Drift Formation of Park (1887) and the Hawera Series of Thomson (1917). The Brunswick Terrace, a smooth, gently sloping coastal plain, falls from 500 ft. to 400 ft., where a scarp leads down to the lower and younger Rapanui Terrace, falling seaward from a height of about 300 ft. (Fig. 1). The cover on both terraces consists of marine sands and conglomerates, interfingering fluviatile deposits, old land surfaces with soils, ash horizons, lignites, and consolidated dune sands. These deposits are preserved on wide interfluves, but have been removed from the valleys of streams deeply entrenched below them.

Pleistocene Ores of the Brunswick Formation

(*a*) *Brunswick Pebbly Sands.*—These, the basal beds of the Brunswick Formation, are poor in magnetite in their lower portions, but magnetite is more abundant at higher horizons. The beds are pebbly, have, in general, a heavy overburden, and are not of high grade. They are thus of little significance as potential ores.

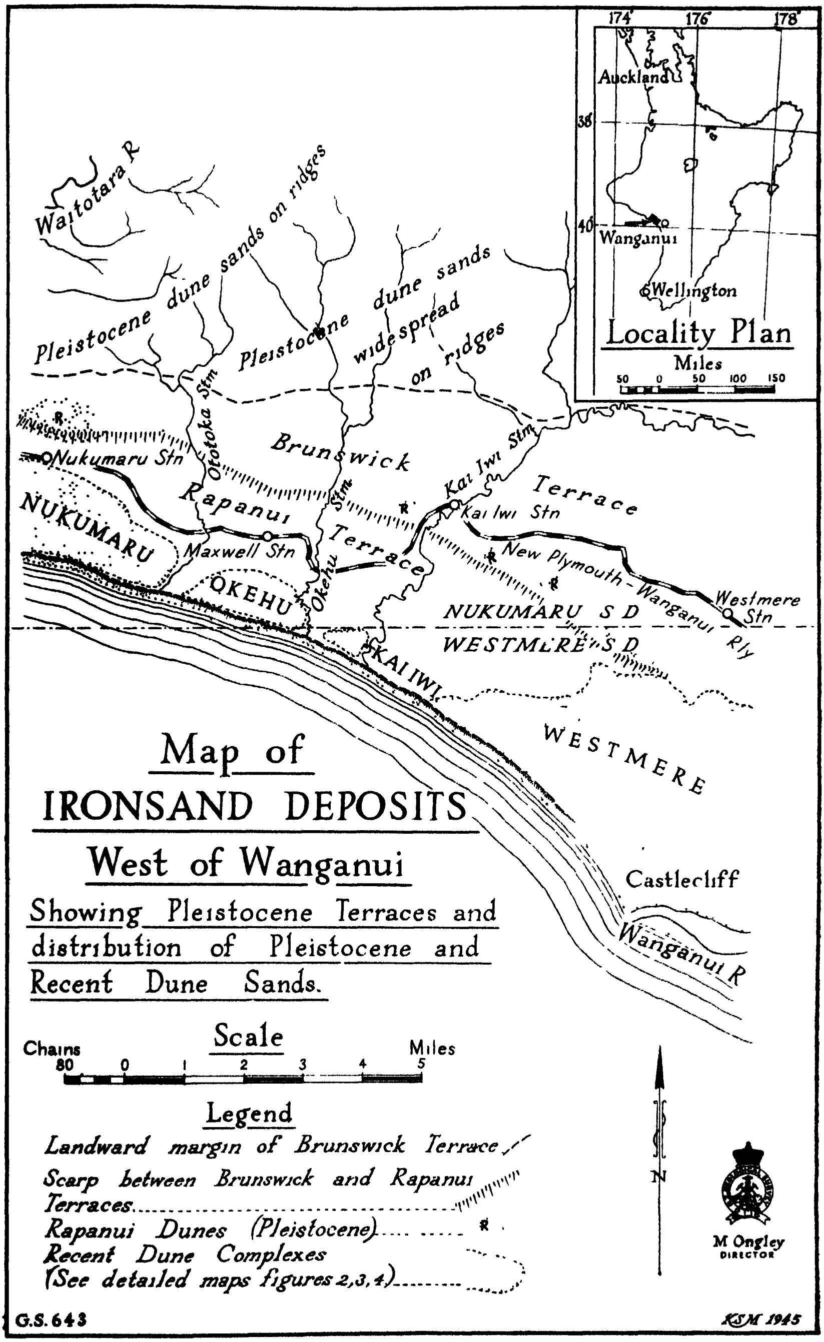
Map of
IRONSAND DEPOSITS
West of Wanganui
Showing Pleistocene Terraces and distribution of Pleistocene and Recent Dune Sands.
Scale
Chains 80 0 1 2 3 4 5 Miles
Legend
Landward margin of Brunswick Terrace
Scarp between Brunswick and Rapanui Terraces
Rapanui Dunes (Pleistocene)
Recent Dune Complexes
(See detailed maps figures 2,3,4)
Locality Plan
Auckland
Wanganui
Wellington
Miles
Waitotara R
Pleistocene dune sands on ridges
Pleistocene dune sands widespread on ridges
Ototoka Stm
Nukumaru Stn
Brunswick
Rapanui
Terrace
Kai Iwi Stm
Kai Iwi Stn
New Plymouth-Wanganui Rly
Westmere Stn
NUKUMARU
Maxwell Stn
OKEHU
Okehu Stm
NUKUMARU S D
WESTMERE S D
KAI IWI
WESTMERE
Castlecliff
Wanganui R
N
M Ongley DIRECTOR
G.S. 643
KSM 1945

FIG. 1.

(*b*) *Brunswick Magnetite-rich Beach Sand.*—Overlying the basal pebbly sands, in places separated from them by fluviatile beds, and elsewhere transgressing on to the Pliocene basement, is a bed of fine-grained, well-sorted, magnetite-rich sands finely current bedded at low angles, with paystreaks rich in magnetite, and with a grading pointing to long-continued beach sorting at a time when little waste was being supplied to the coasts. The bed varies from under 10 ft. to over 20 ft. in thickness. The sample analysed (Table I, No. 13) has a high percentage of magnetite (91 per cent.), and though this is an exceptionally high grade the sand is considered good ore. The quantity of sand in the area is in the order of 150,000,000 tons, but, in general, it lies below a heavy overburden of lower-grade dune sands and under good farming country, so the possibility of its use as ore is remote.

(*c*) *Brunswick Dune Sands.*—With the exception of a superficial layer of soil and ash shower deposit, the upper 10 ft. to 40 ft. of Brunswick sediment is composed of coarse dune-bedded sands similar in their magnetite content to the Recent dune sand. The amount of such sand in Westmere and Nukumaru Survey Districts is in the order of 400,000,000 tons.

On interfluves rising above and north of the Brunswick Terrace, extensive deposits of wind-blown ironsand mantle an old land surface developed in Pliocene rocks up to a height of 1,100 ft. These sands are believed to have been deposited at about the same time as the dune sands of the Brunswick Terrace. The sands are in large quantities, but are limited to interfluves in deeply dissected country separated by valleys with relief of about 500 ft., and most of the deposits are difficult to get at.

Brunswick dune sands contain from 10 per cent. to 25 per cent. magnetite (Table I), the mean of five samples being 15 per cent. An additional sample (No. 22) from a height of 950 ft. on the Rangitatau West Road is believed to have undergone water sorting, for it is well graded and contains 77·5 per cent. of magnetite.

Pleistocene Ores of the Rapanui Formation

(*a*) *Rapanui Beach Sands.*—The basal beds of the sedimentary cover of the Rapanui Terrace are similar to the lowest beds of the Brunswick Formation, but are much richer in magnetite. Pebbly sands averaging about 15 ft. in thickness give way to about 10 ft. of well-sorted beach sands underlying a fossil land surface with lignite, ash deposits, and trunks of trees.

As the sands crop out rarely except on the coast, they are difficult to estimate, but reach the general order of 150,000,000 tons. The only sample of Rapanui beach sands analysed contained 17·3 per cent. magnetite (No. 28, Table I).

(*b*) *Rapanui Dune Sands.*—A bed of indurated dune sand of varying thickness (0 ft. to 25 ft.) overlies the lignite horizon in the Rapanui Formation. There appear to be some 100,000,000 tons to 200,000,000 tons underlying the surface of the Rapanui Terrace with a shallow soil overburden, but, owing to poverty of outcrops, data on the inland part of the section are inadequate.

A discontinuous belt of low dune hillocks caps the scarp separating the Rapanui from the Brunswick Terrace. These dunes (Fig. 1) are believed to be contemporaneous with the dune sands underlying the Rapanui Terrace. The amount of sand contained in these Rapanui dunes is not large, compared with the quantities of other Pleistocene ironsand.

Dune sands of the Rapanui Formation contain 11·8 per cent. to 18·9 per cent. of magnetite, the mean of four determinations being 16·3 per cent. (Table I).

SUMMARY OF PLEISTOCENE IRONSANDS

—	Approximate Tonnage ($\times 10^6$)	Mean Percentage of Magnetite.	Approximate Tonnage of Magnetite ($\times 10^6$).
Brunswick beach sands	150	91 (one sample only)	30 to 130
Brunswick dune sands	400	15	60
Rapanui beach sands ..	150	17·3	25
Rapanui dune sands ..	100 to 200	16·3	16 to 32
Total magnetite ..	..	..	131 to 247

No high degree of accuracy is claimed for the above figures, which nevertheless fairly represent the magnitude of the Pleistocene deposits. In some cases the number of determinations of magnetite is too small to give a fair representation of the quality of the sand.

Utilization of the Pleistocene sands would entail the destruction of about 20 square miles of first-class farming-land, and it is thus unlikely to be exploited. It may be objected that a mobile separation plant could replace rejected material (largely silicate minerals), which, when fixed, could become a reasonably good soil, but much of the fertility of the land is due to a thin superficial layer of andesitic ash (probably the " Egmont shower " of Grange and Taylor, 1933) which overlies the Brunswick ironsands, and this would be difficult to replace.

Although the Pleistocene ores are unlikely to be worked as a whole, utilization of Recent dune sands where they overlie Rapanui beds could be readily extended to the underlying Pleistocene consolidated sands.

RECENT IRONSAND DEPOSITS

The Recent ironsands consist of a narrow thin strip of beach sands veneering the wave-cut platform below the sea-cliffs, and of much larger quantities of sand in multicycle dunes capping the cliffs in four areas separated by the courses of the Kai Iwi, Okehu, and Ototoka Streams (Fig. 1).

(a) Recent Beach Sands

The beach from Nukumaru to Castlecliff consists of a veneer of sand over a wave-cut platform which is exposed in places. The sand veneer is usually over 3 ft. in depth, and at Castlecliff becomes deeper where sand transported from the north encroaches upon the submarine (possibly somewhat subsided) trough of the Wanganui River. Sand was penetrated by piles for the North Mole to depths of over 30 ft.

The dominant longshore drift is to the south-eastward and beach sand is moving slowly southward, forming extensive bars north of the mouths of smaller streams which flow athwart its course. The sand is delayed by such streams, but periodic changes in the outlets of a stream, which breaks through the neck of a bar at times of flood, allows the sand of the bar to resume its south-eastward movement.

The heavier fractions in the sand, including magnetite, do not travel so rapidly as the lighter silicate minerals, and with increasing distance from Egmont the percentage of magnetite in beach sand falls from 65 per cent. in one sample from Nukumaru (Table 1, No. 27) to 4·2 per cent. at Castlecliff (mean of three samples). The rapidity of this decrease in quality of the beach ironsand is related not only to the increasing distance from

the source, but also to dilution of Egmont-derived sand by poorly ferriferous sediments brought down by the Wanganui River.

Against the North Mole at the mouth of the Wanganui River sand has built out to a distance of over 20 chains since the mole was built in 1884 (judging from photographs taken at that time). The effects of this progradation extend for about two miles north of the river mouth, but the amount of sand added in the period of sixty years, though considerable, is but a fraction of the total amount of sand that has travelled south to Castlecliff in that period, for large amounts have been blown inland or carried seaward by the Wanganui River.

The quantities of beach sand in the area covered by this paper (Table II) are estimated on the inference of an average depth of 3 ft. of sand on the beach strip, the area of which has been determined from available maps and from aerial photographs.

(b) Recent Dune Sands

The Recent dune sands form a discontinuous coastal belt, interrupted by the valleys of the main streams, and extending inland from the coastal cliffs for distances of one-half to three miles. The dunes overlie the surface of the Rapanui Terrace or, locally, terraces at lower levels cut by the Wanganui River. The Kai Iwi, Okehu, and Ototoka streams separate four unequally sized dune complexes which have been given names for convenience of description (Fig. 1).

(1) *Nukumaru Dune Complex.*—The Nukumaru dune complex (Figs. 2 and 5) lies between the coast and the railway (a distance of up to a mile and a half) and extends from the western boundary of Nukumaru Survey District (the limit of the present survey) to the Ototoka Stream, a distance of three miles. It covers approximately 2,200 acres. In this area an old generation of fixed dunes has been attacked and deflated along its seaward margin, and the sand so produced is advancing as a median belt of active dunes overwhelming, in a landward direction, fixed dunes of the older generation.

The active dunes form a discontinuous belt averaging 30 chains in width, generally parallel to the coast, and made up of a series of longitudinal tongues advancing north-eastward from narrow "sand plains" where water table is exposed, and separated from each other by narrow sinuous clefts defined by opposing sandfall faces.

The landward belt of fixed dunes, towards which the active belt is advancing, consists of parabolic dune ridges separated by inter-dune flats. Each parabolic dune is hairpin-shaped in plan, roughly symmetrical in cross-section, and increases in both surface area and height from the trailing "wings" to the apex of the hairpin. The crests of the ridges are irregular in height and the margins are usually finely scolloped. The parabolic dunes rise from the flat surface of the Rapanui Terrace; a veneer of unconsolidated sand usually covers such flats, and the dune ridges themselves, though fixed, are of unconsolidated sand. The parabolic dunes have an axis—*i.e.,* the bisectrix of their two arms varying in direction from N. 80° E. to N. 120° E., but the dominant direction is due east. The maximum height of each ridge varies from 35 ft. to 75 ft. above the inter-dune flats and the greatest width of their surface plan from 2 chains to 10 chains. They show a tendency to be "nested."

The seaward belt of deflated dunes at Nukumaru is composed of an irregular jumble of ridges, knolls, and flats, incompletely fixed by marram, *Spinifex,* and lupin, and including small blow-outs and active dunes. In places wind scour has exposed the indurated ironsands of the Rapanui Formation, and locally, near the coast, the whole thickness of Rapanui beds has been deflated, and a "lag gravel" of andesite and quartzite pebbles (locally forming dreikanter) from the Rapanui conglomerates rests on the surface of Pliocene shell rock.

(2) *Okehu Dune Complex* (Fig. 3).—Between the mouths of the Okehu and Ototoka streams a roughly semicircular area of dune sands (874 acres) extends inland from the coast for a maximum distance of 65 chains. Two separate bodies of active sand are similar to the Nukumaru active dune belt, except that they have overwhelmed any fixed dunes of a previous generation which may have existed along the landward edge of the complex.

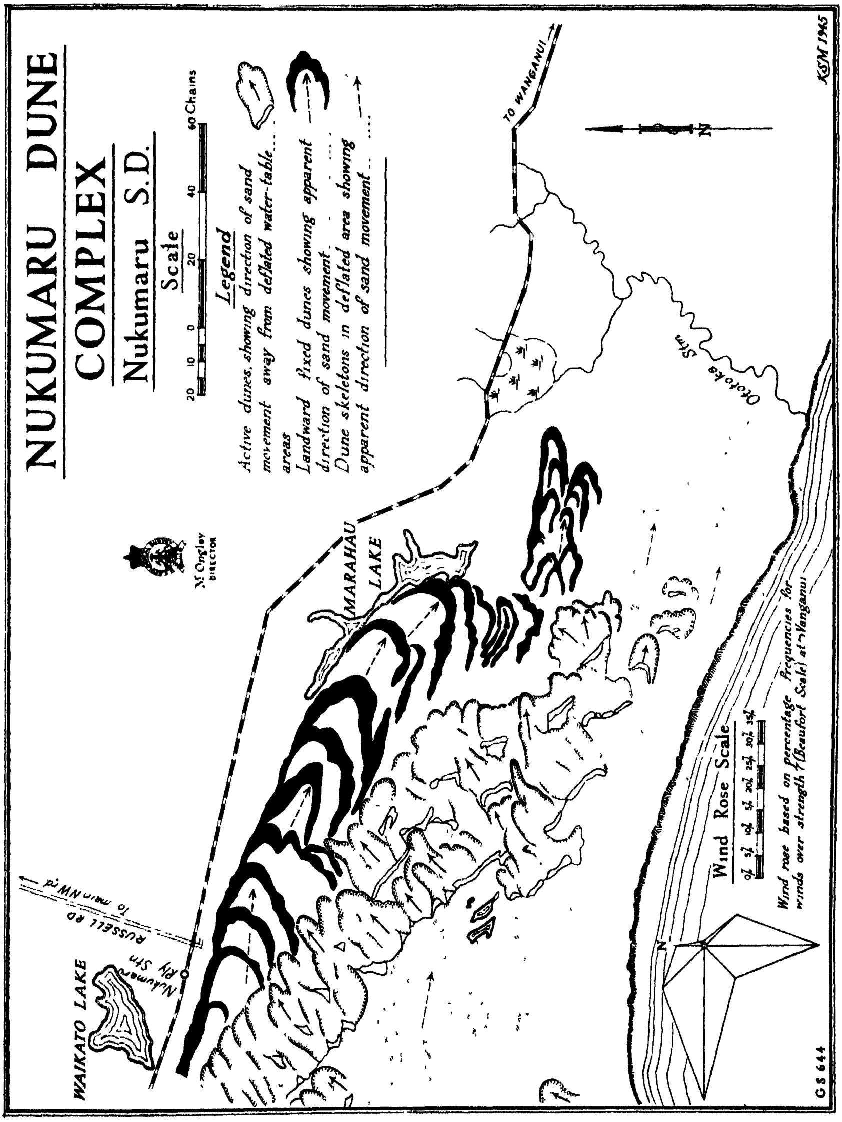

FIG. 2.

(3) *Kai Iwi Dune Complex* (Fig. 3).—The Kai Iwi dune complex, between the mouths of Okehu and Kai Iwi streams, is small in area (130 acres) and consists of irregular hummocky deflated dunes mainly fixed by lupin, with a few active patches along the cliff top.

(4) *Westmere Dune Complex* (Figs. 4 and 6).—This name has been given to the extensive dune ridges occupying an irregularly triangular area between the Wanganui Valley, the coast, and the Westmere–Rapanui Road. From the Rapanui Terrace the land falls by a series of terraced steps which are apparently sub-Rapanui terraces formed by the Wanganui River. The dunes lie for the most part on the sub-Rapanui surfaces, but have reached the Rapanui Terrace itself between Lakes Westmere and Virginia.

An irregular belt of fixed dunes foots the low scarp separating the Rapanui Terrace from a somewhat lower surface to the south of Rapanui Road, and similar irregular dune ridges extend across the Great North-west Road towards Lake Virginia. Occasionally parabolic and longitudinal forms with an east-west axis occur, but the original outlines are in most cases hard to define.

A strip of country extending west of Westmere and Lake Virginia is occupied by large parabolic dunes with a width, in places, of up to 8 chains or 10 chains, and with heights above the flat inter-dune surfaces of up to 70 ft. (mean, 40 ft.). Successive parabolic dunes are frequently nested, one within the other. In size and form they resemble the landward belt of fixed parabolic dunes at Nukumaru. Westward towards the sea-cliff, and southwards on successively lower terrace levels, the parabolic dunes are narrower in surface plan and lower in height, and linear longitudinal dunes directed about 100° E. become the dominant form. Some of such longitudinal ridges are only a chain wide, range from 15 ft. or 20 ft. high to nothing, and are three-quarters of a mile long.

All the dunes described are fixed by vegetation, except where local human influence has bared the sand. Only near the coast are there small areas of deflated dunes and local "blow outs" near the cliff edge where active sand is exposed.

Wherever sections have been seen, a few feet of sand veneers the indurated Pleistocene sand or river terrace deposits which underlie the inter-dune flats. The water-table may be near or at the surface on such flats, and swamps are occasionally present.

QUANTITIES OF IRONSAND IN RECENT DEPOSITS

Beach Sand

Between Fishing Rock, Nukumaru, and the North Mole, Castlecliff, there are twelve miles and a half of coast-line along which ironsand beaches are generally present below the cliffs. At Nukumaru beach, sand contains up to 65 per cent. magnetite, but the grade falls to 31 per cent. at Kai Iwi, 8·5 per cent. at a point two miles and a quarter north-west of Castlecliff, and 4·2 per cent. (mean of three determinations) at the North Mole, Castlecliff (see Table I) Quantities of beach sand are based on measurement from aerial photographs and other surveys of the area of beach, on the inference that beach sands extend to an average depth of 3 ft. Quantities are presented under two headings:—

(*a*) From Castlecliff to the mouth of Kai Iwi Stream.
(*b*) From Kai Iwi to Nukumaru.

Dune Sands

In the case of dune sands, quantities are estimated by different methods for different areas. In the Nukumaru complex the seaward belt of deflated dunes is assessed by allowing a mean thickness of 6 ft. of sand over the whole area, a figure which is believed to be low, as some irregular ridges rise 40 ft. above their base, and it is only in limited areas that the Pleistocene and Pliocene rocks below the dunes have been swept clear of sand.

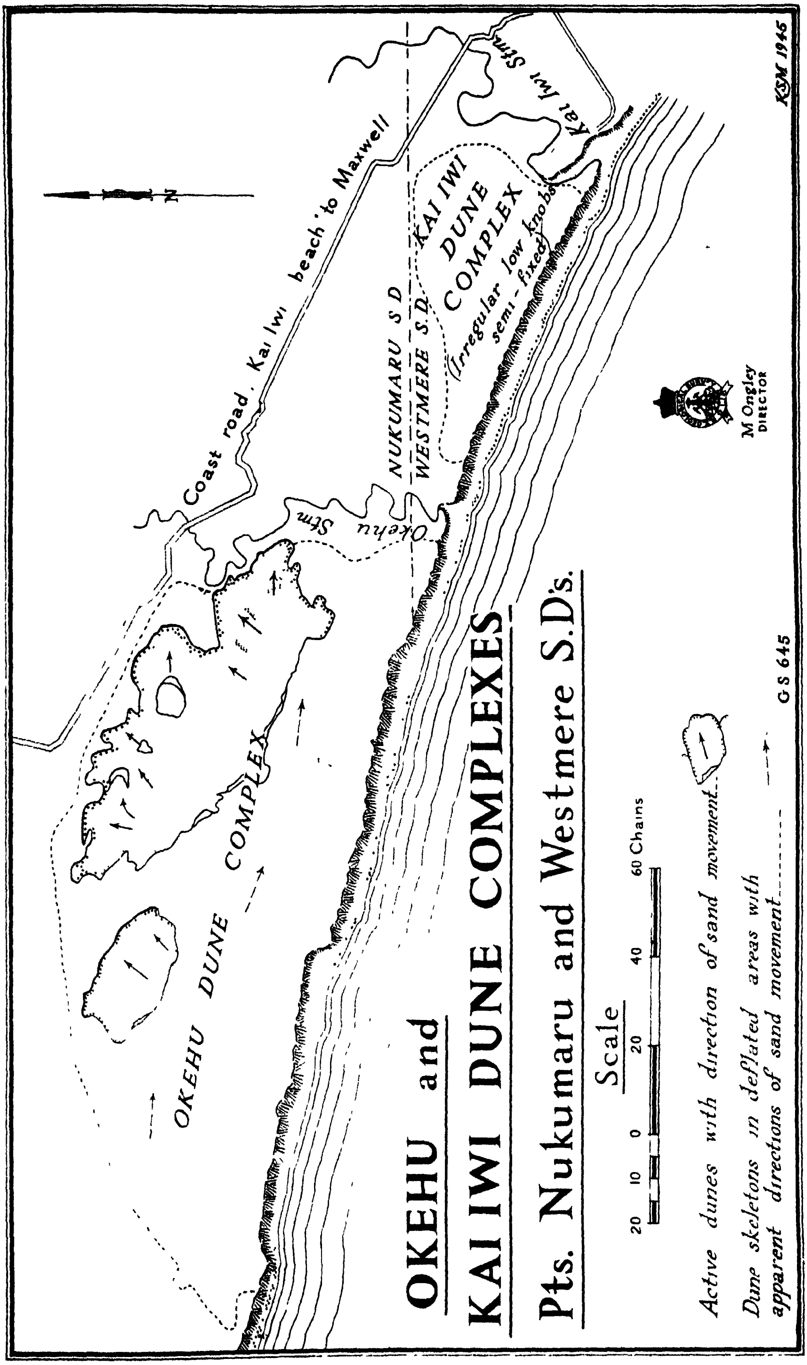
OKEHU and
KAI IWI DUNE COMPLEXES
Pts. Nukumaru and Westmere S.D's.
Scale
20 10 0 20 40 60 Chains
Active dunes with direction of sand movement
Dune skeletons in deflated areas with apparent directions of sand movement
Coast road. Kai Iwi beach to Maxwell
NUKUMARU S.D
WESTMERE S.D.
KAI IWI DUNE COMPLEX
(Irregular low knobs semi-fixed)
Kai Iwi Stm
Okehu Stm
OKEHU DUNE COMPLEX
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FIG. 3.

The quantities of sand in the active dune belt is estimated from the formula $q = \sum \frac{(h - b)}{3n} (a)$, where h = spot heights on dune ridges, b = base of dune at the spot height, interpolated from geological considerations, n = number of spot heights, and a = area covered by active dune. The landward fixed dune ridges are similarly estimated and a depth of 3 ft. of sand allowed on the inter-dune flats between the ridges, as justified by exposures in ditches. The Okehu and Kai Iwi dune complexes have been estimated in the same way, allowing a mean depth of 6 ft. on the deflated and semi-fixed areas and from the formula expressed above for active belts.

The large Westmere dune complex was divided primarily into semi-fixed and deflated areas of negligible agricultural value and fixed dune in areas of pasture, plantations, golf-links, &c. "Built-up" areas adjacent to the Wanganui suburbs of Castlecliff and Mosstown have been omitted from consideration. The dunes were assessed by calculating the total area occupied by ridges and utilizing the known heights of dune ridges and of the surfaces above which they rise. Three feet of sand has been allowed on the flats between ridges, and these quantities have been assessed separately, as the flats are better agricultural land than the ridges.

Nineteen grab samples of sand from different dune complexes and different parts of the complexes have been analysed by electro-magnetic separation and the magnetic fraction submitted to grain count by Dr. C. O. Hutton, Petrologist, N.Z. Geological Survey. The percentage of magnetite in the sand has been assessed by multiplying the magnetic fraction percentage (which is a percentage by weight) by the percentage of magnetite in the magnetic fraction (which is a percentage by grain count). It is thus assumed that the mean weight of the usually small magnetite grains approximates that of the usually more bulky silicate grains in the magnetic fraction. The results, for individual samples, are presented in Table I.

The tonnage of sand (Table II) is obtained by multiplying the cubic yardage of sand (derived as indicated in the above paragraphs) by a factor varying from about 1·5 to 1·75, according to the mean magnetite content of sand from the area concerned. The tonnage of magnetite is obtained by multiplying the tonnage of sand by the mean percentage of magnetite in samples from the area. It should be noted that the results are liable to several sources of error and it is not possible to state the limits of error on the information avàilable. For instance, in three samples collected from one active dune (Table I, Nos. 35, 36, and 37) within an area of less than an acre, magnetite ranges from 5·1 per cent. to 21·9 per cent., and without knowledge of the internal structure of the dunes, only arithmetic means of such grab samples can be used in estimating quantities of magnetite.

QUALITY OF IRONSAND

Table I presents the results of Dr. Hutton's electromagnetic and grain count analyses of Wanganui sands. These results have been used in the assessment of quantities of magnetite, but to allow detailed comparison of the magnetic fractions of the sand in the Wanganui area with sands previously studied by the Mines Department at Patea (unpublished investigations noted by Mason, 1945, p. 228) four samples of Wanganui sand were submitted to the Dominion Laboratory for quantitative determinations of soluble iron.

Table III presents the results of the analyses by Mr. J. J. S. Cornes, Dominion Laboratory, together with analyses of sand from Patea, Wairoa Survey District, and Whenuakura River mouth. The analyst notes that, in the case of the Wanganui samples, "each of the four original sands was

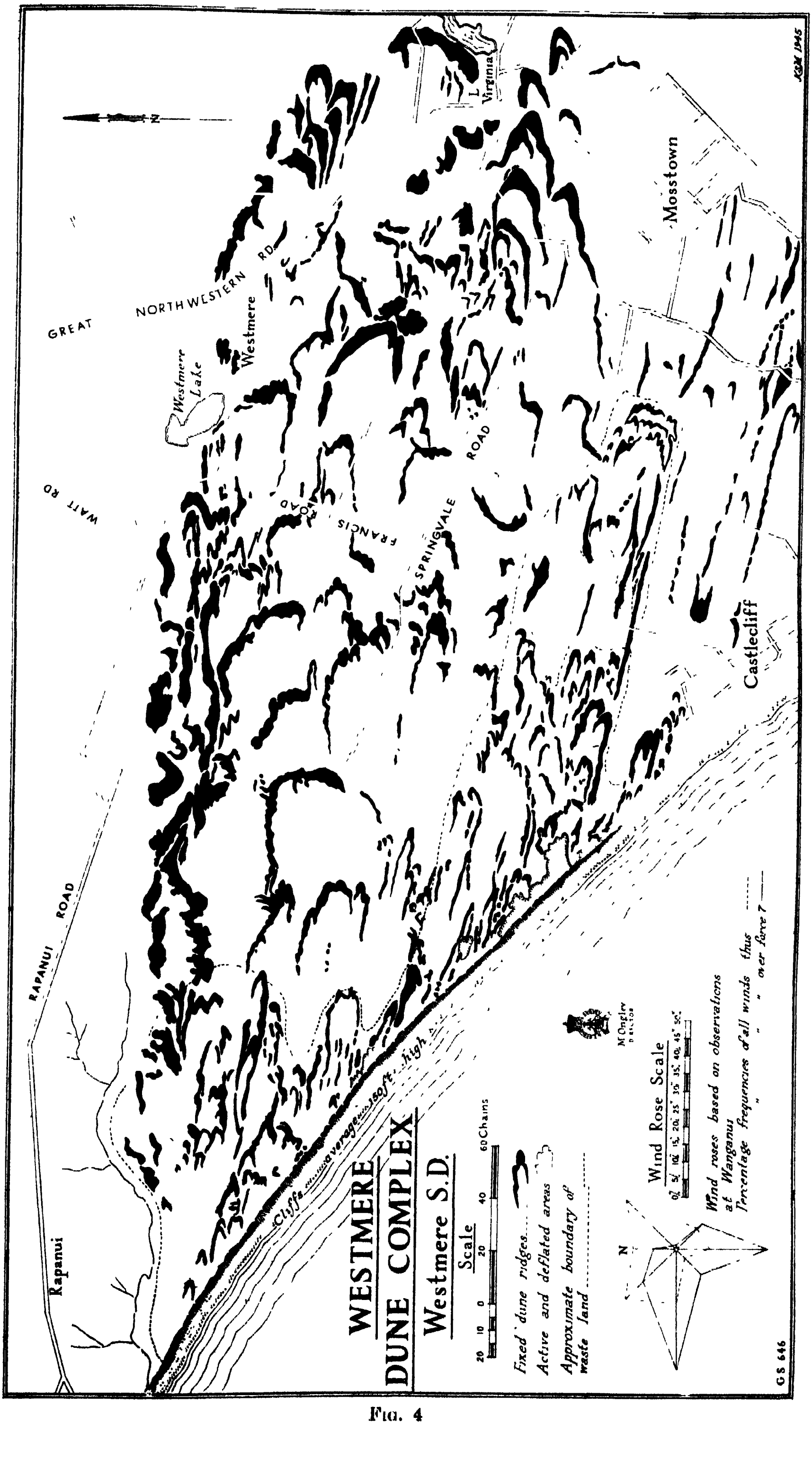
WESTMERE
DUNE COMPLEX
Westmere S.D.
Scale
20 10 0 20 40 60 Chains
Fixed dune ridges
Active and deflated areas
Approximate boundary of waste land
Wind Rose Scale
Wind roses based on observations at Wanganui
Percentage frequencies of all winds thus
" " over force 7
N
Rapanui
RAPANUI ROAD
WAIT RD
GREAT NORTHWESTERN RD
Westmere Lake
Westmere
FRANCIS ROAD
SPRINGVALE ROAD
L. Virginia
Mosstown
Castlecliff
Cliffs average 150 ft high
GS 646

FIG. 4

separated by means of a weak magnet into two fractions, one strongly magnetic, and the other, the remainder, much of which was feebly to moderately magnetic. Both fractions, after fine grinding, were analysed for iron soluble in concentrated hydrochloric acid containing stannous

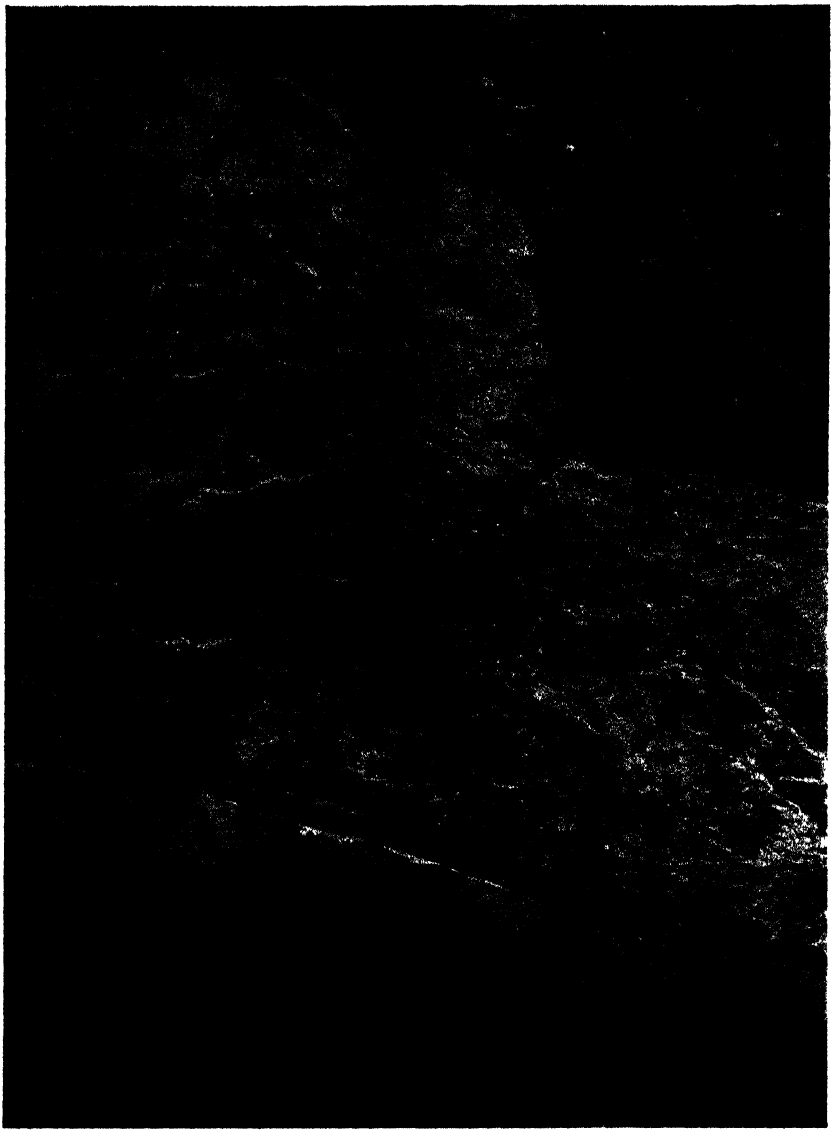

FIG. 5.—Aerial photograph of part of Nukumaru dune complex. Active dunes (*a*) advancing north-eastward exposing the water-table as dark strips. Older fixed parabolic dunes (*b*) have apparently advanced in an east-south-east direction. Deflated dunes along coast and in bottom right corner.

chloride, which would dissolve free magnetite or magnetite inclusions in the silicates. For comparison, some results previously found for composite samples made from samples of sand from Patea-Wairoa beaches are given (Table III (*a*), (*b*), (*c*), (*d*)). In this case the percentage of acid-soluble

iron had been determined in the original sand and in the strongly magnetic fraction, from which data the soluble iron in the feebly magnetic fraction has now been calculated as per cent. by weight on the complete sand."

The strongly magnetic fraction in the Patea-Wairoa sands is in general greater than in the Wanganui sands, but the percentage of acid-soluble

FIG. 6.—Aerial photograph of part of Westmere dune complex north of Castlecliff, showing east-south-east orientation of fixed longitudinal dune ridges and of elongate parabolic dunes.

iron in the magnetic fractions from both areas is so similar that it is fair to consider the magnetic fractions of the sands from the two areas of equivalent ore value.

The results by chemical analysis cannot be compared precisely with the results by electromagnetic and grain count analysis, since different magnetic fields may have been used in the two cases, and, in the chemical analyses, silicates with magnetite inclusions could not be eliminated from the magnetic fraction.

In his reports on Patea and Fitzroy sands, C. O. Hutton has shown (1940, p. 195B; 1945, p. 294) that screening prior to electromagnetic separation will result in a much more effective concentration of magnetite than can be obtained by magnetic separation alone. The same may be said of Wanganui sand. The following is the result of mechanical analysis of 100 g. of a typical sand (sample No. 41) and the number of grains of magnetite in a 100 g. of the separate fractions. Dr. Hutton, in his manuscript report to the writer, notes that by preliminary screening through 60 mesh, a good concentrate for subsequent electromagnetic separation may be obtained.

Screen.	Weight, per Cent	Percentage of Iron-ore
−10 + 18	0·32	0
−18 + 35	5·00	4
−35 + 60	34·02	4
−60 + 120	49·40	4·5
−120 + 230	10·52	74
−230	0·62	78

ACKNOWLEDGMENTS

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REFERENCES

BAGNOLD, R. A. (1941): "The Physics of Blown Sand and Desert Dunes." Methuen and Co., Ltd., London, p. 265.

COCKAYNE, L. (1911): Dune Areas of New Zealand, *N.Z. Parl. Paper, C.-13.*

COTTON, C. A. (1942): "Climatic Accidents in Landscape-making." Whitcombe and Tombs, Ltd., New Zealand, p. 354.

GRANGE, L. I., and TAYLOR, N. H. (1933): Field-work on Soils of Western Taranaki. *Dept. S.I.R. 7th Annual Report*, 34–5.

HUTTON, C. O. (1940): The Titaniferous Ironsands of Patea, with an Account of the Heavy Residues of the Underlying Sedimentary Series. *N.Z. J. Sci. & Tech.*, *21*, 190B–205B.

——— (1945): The Ironsands of Fitzroy, New Plymouth. *N.Z. J. Sci. & Tech.*, *26 (Sec. B)*, 291–302.

MADDIGAN, C. T. (1936): The Australian Sand-ridge Deserts. *Geog. Rev.*, 205–27.

——— (1937): A Review of the Arid Regions of Australia and Their Economic Potentialities. *Rep. 23rd Meeting Aust. and N.Z. Assn. for the Advancement of Science*, Auckland Meeting, 375–97.

MASON, BRIAN (1945): The Utilization of New Zealand Ironsands as a Source of Iron, Titanium, and Vanadium. *N.Z. J. Sci. & Tech.*, *26 (Sec. B)*, 227–238.

MELTON, F. A. (1940): A Tentative Classification of Sand Dunes—Its Application to Dune History in the Southern High Plains. *J. Geol.*, *48*, 113–74.

PARK, J. (1887): On the Geology of the Western Part of Wellington Provincial District and Part of Taranaki. *Rept. Geol. Explor. during 1886–1887*, *18*, 24–73.

PHARAZYN, R. (1869): Remarks on the Coast Line between Kai Iwi and Waitotara, on the West Coast of the Province of Wellington. *Trans. N.Z. Inst.*, *2*, 158–60.

THOMSON, J. A. (1917): The Hawera Series or the So-called "Drift Formation" of Hawera. *Trans. N.Z. Inst.*, *49*, 414–7.

TABLE I.—ELECTROMAGNETIC AND GRAIN COUNT ANALYSIS OF IRONSANDS WEST OF WANGANUI RIVER (by DR. C. O. HUTTON, PETROLOGIST)

Sample No.	Locality.	Attracted in Electro-magnetic Field (by Weight).	Magnetite in Attracted Fraction.	Magnetite in Total Sand.
	Pleistocene Ironsands	Per Cent.	Per Cent.	Per Cent.
13	Brunswick magnetite beach sands, Ototoka section ..	93·90	97	91·0
22	Brunswick sand at 950 ft., Rangitatau West Road ..	81·8	88	77·5
12	Brunswick dune sand, Okehu section	25·50	65	16·6
15	Brunswick dune sand, Ototoka section	37 94	66	25·6
16	Brunswick dune sand, Ototoka section	14·60	67	9·8
19	Brunswick dune sand, 120 chains south of Puketarata Trig., Nukumaru Survey District	9 80	82	8·0
24	Brunswick dune sand, at 1,000 ft. on Rangitatau West Road	26 10	67	17·5
28	Rapanui beach sand, Nukumaru Beach	29 40	59	17·3
8	Rapanui dunes at Mount Smith	30·40	61	18·5
29	Rapanui dune sand, Nukumaru Beach	28 10	67	18·9
39	Rapanui dunes, 1 mile north of Nukumaru station ..	32 94	49	16·2
49	Rapanui dune, 44 chains north of Seafield Trig., Westmere Survey District	21 40	55	11·8
	Recent Beach Sands			
1	Mid tide, beach immediately under North Mole, Castlecliff	18 90	80	15·02
2	High tide, beach at North Mole, Castlecliff ..	11·96	13	1.55
21	Dug sample depth 3 ft. 6 in., at North Mole, Castlecliff	12 60	21	2·65
4	High tide mark, 2¼ miles north-west of Wanganui River mouth	16·40	52	8·53
26	High-tide mark, Kai Iwi Beach	43·10	74	31·8
*27	Mid-tide mark, Nukumaru Beach	74·80	87	65·0
	Recent Dune Sands			
	Nukumaru dune complex—			
30	Active dune near coast, 120 chains at 195 from Nukumaru Railway-station	33 50	48	16·1
31	Interdune flat in deflated area, 105 chains south of Nukumaru Railway-station	28 40	71	20 2
32	Ridge in deflated area 90 chains south of Nukumaru Railway-station	29 84	66	19·7
*33	Sand plain behind active dune, 58 chains south of Nukumaru Railway-station	32 94	62	20·3
*35	Sandfall of active dune	25·56	20	5·1
36	Crest of active dune	37 80	58	21·9
37	Tail of active dune, 50 chains south of Nukumaru Railway-station	27·20	54	14·7
38	Fixed dune, 20 chains south-east of Nukumaru Railway-station	35·80	56	20·0
	Okehu dune complex—			
41	Seaward edge, active dune	35·10	79	27·8
42	Landward edge, active dune	30·64	63	19·3
	Westmere dune complex—			
3	8 chains from high-tide mark, Castlecliff ..	12·30	40	4·7
5	Top of active ramp to cliff top, North end, Castlecliff Beach	15·10	70	10·6
6	Fixed dune ridge, 88 chains at 250° from Day Trig., Westmere Survey District	20·20	85	18·7
*7	Fixed dune ridge, 72 chains at 215° from Day Trig.	19·24	51	10·0
43	Fixed dune ridge, 72 chains at 190° from Day Trig.	27·44	51	13·9
44	Fixed dune, 48 chains at 118° from Day Trig. ..	26·62	46	12·2
45	Fixed dune ridge, 48 chains at 153° from Westmere Trig., Westmere Survey District	31·20	56	17·5
47	Fixed dune, 4 chains south of Westmere Trig. ..	22·80	27	6·1
48	Fixed dune, 60 chains at 103° from Westmere Trig.	23·50	35	8·2

* Chemical analyses for acid-soluble iron in samples marked thus are presented in Table III.

TABLE II.—ESTIMATED QUANTITIES OF TITANOMAGNETITE-IRONSAND ORE IN DEPOSITS OF RECENT AGE IN AREA WEST OF WANGANUI RIVER

Area and Type of Deposit.	Approximate Tonnage of Ironsand.	Mean Percentage of Magnetic Fraction.	Approximate Mean Percentage of Titano-magnetite in Total Sand	Approximate Tonnage of Titano-magnetite.
I. Beach sands—				
* Castlecliff to Kai Iwi	1,820,000	20·6	14·6	275,720
* Kai Iwi to Nukumaru	1,020,000	58·9	48·4	493,680
Total, beach sand	2,840,000	..	.	769,400
II. Nukumaru dune complex—				
* Deflated dune belt	13,000,000	30·6	18·7	2,431,000
* Active dune belt	35,700,000	30·8	15·5	5,433,500
Fixed dune belt	8,800,000	35·8	20·0	1,760,000
Total, Nukumaru dunes ..	57,500,000	..	..	9,624,500
III. Okehu dune complex—				
* Active dune belt	10,800,000	32·9	23·6	2,448,800
* Deflated dune belt	9,630,000			2,272,680
Total, Okehu dunes .. .	20,430,000	..	.	4,721,480
* IV. Kai Iwi dune complex	2,020,000	No samples: taken as 18 per cent. magnetite		363,600
V. Westmere dune complex -				
* Active deflated, semi-fixed dunes of negligible agricultural value	15,000,000	22·04	12·1	1,815,000
Fixed dune ridges in pasture	19,565,000			2,367,365
Inter-dune flats in pasture	26,000,000			3,146,000
Total, Westmere dunes ..	60,565,000	..	..	7,328,365
Total in areas of negligible agricultural value (sum of items marked *)	88,990,000	..	..	15,533,980
Grand total	143,355,000	..	..	22,807,345

* Areas of negligible agricultural value.

TABLE III.—ANALYSES FOR ACID-SOLUBLE IRON IN STRONGLY MAGNETIC AND RESIDUAL FRACTIONS OF IRONSAND FROM WANGANUI DISTRICT AND FROM PATEA, WAIROA SURVEY DISTRICT, AND WHENUAKURA RIVER, BY DOMINION LABORATORY (J. J. S. CORNES, ANALYST)

—	L. 1654				Composites			
	–1	–2.	–3.	–4	(a)	(b)	(c)	(d)
Strongly magnetic fraction in 100 g. of original sand	7·8	52·0	12·4	2·2	26·8	40·9	32·4	42·8
Acid-soluble Fe in 100 g. of strongly magnetic fraction	54·1	57·6	54·8	49·8	53·6	55 1	53 1	54·2
Acid-soluble Fe of strongly magnetic fraction in 100 g. of original sand	4 2	30·0	6·8	1·1	14·4	22·5	17·2	23·2
Feebly or non-magnetic fraction in 100 g. of original sand	92 2	48·0	87·6	97·8	..	..	..	..
Acid-soluble Fe in 100 g. of feebly or non-magnetic fraction	2·8	6 4	3·0	2·1	.	..	..	..
Acid-soluble Fe of feebly or non-magnetic fraction in 100 g. of original sand	2 6	3 1	2·6	2·1	3 1	4·9	4·3	12·0
Total acid-soluble iron in 100 g. of original sand	6 8	33 1	9·4	3·2	17 5	27·4	21·5	35·2

Specimen No

L. 1654-1 .. .. (= No. 7 of Table I.) Westmere Survey District; fixed dune 72 chains at 215 from Day Trig.

L. 1654-2 .. .. (= No. 27 of Table I.) Nukumaru Survey District beach sand, Nukumaru Beach.

L. 1654-3 .. .. (= No. 33 of Table I.) Nukumaru Survey District sand plain; 50 chains south of Nukumaru Railway-station.

L. 1654-4 .. .. (= No. 35 of Table I.) Nukumaru Survey District active dune: 50 chains south of Nukumaru Railway-station

(*a*) .. .. } Carlyle Survey District, Patea. Composites made up from Dominion
(*b*) .. .. } Laboratory specimens, E. 1804 (1–77).

(*c*) .. .. Wairoa Survey District Composite from Dominion Laboratory, specimens E. 2547 (1–40).

(*d*) .. .. Wairoa Survey District, Whenuakura River. Composite from Dominion Laboratory specimens E. 2548 (1–33).

The magnetic fraction of sample L. 1654–2, comprising 52 per cent. of the original sand and containing 57·6 per cent. Fe, was analysed for vanadium and for titanium dioxide, with the result:—

Vanadium (V) as metal, per cent. 0 24
Titanium dioxide (TiO_2), per cent. .. .. 8·05

The Wanganui sands are therefore very like other Taranaki black sands.

APPENDIX

DUNE FORM AND WIND DIRECTION

The dunes of the Wanganui coast fall into four main groups:—

(1) Actively advancing source-bordering lea dunes, parallel to the coast and normal to the general direction of sand movement. These are made up of a close array of longitudinal tongues in parallel series, the general direction of movement being normal to the elongation of the whole belt (Cotton, 1942, pp. 106–7). Individually the longitudinal tongues are low and rounded, their fronts fan-like but not particularly steep, their upwind slopes gentle and tailing off into narrow "sand plains" (Cockayne, 1911, p. 14), deflated flats where the water-table has been exposed and which stand out clearly as dark areas in the aerial photographs (Figs. 5 and 6). Laterally the longitudinal ridges are almost all steep-sided to the north, where sandfall slopes are developed, forming a narrow sinuous cleft between one ridge and the next. The southern boundaries of the ridges are usually gentler, but in places strong sandfalls are developed.

The active dunes of the Nukumaru and Okehu complexes fall into this category. Comparison with the wind direction percentage frequencies (kindly supplied by the Director of Meteorological Services) shows that the individual tongues making up such active dunes are advancing parallel to the resultant direction, bisecting the angle between the two dominant strong wind directions.* The structure of such longitudinal dunes, which are elongated parallel to the resultant axis of two storm wind directions, is discussed by Bagnold (1941, p. 224, Fig. 79), who includes them in the general category of "seif dunes."

(2) Parabolic fixed dunes, best exemplified by the landward belt at Nukumaru, and also in the Westmere dune complex. Parabolic dunes are generally regarded as "blow out" features resulting from the excavation of a broad and expanding hollow down to the water-table due to local destruction of vegetal cover and the building of a ringlike mound in advance of the blow-out. Parabolic dunes have also been described as accretion forms. The absence of "active" parabolic dunes in the Wanganui district inclines the writer to Melton's (1940, p. 126) view that they are the result of deflation in dune areas fixed by vegetation. Melton (p. 134–5) believes that "cross winds of equal effectiveness . . . do not produce the simple round, oval, and elongate blow-outs . . . formed under the more simple conditions" (when the effective sand-moving wind blows with constant direction). It seems difficult to reconcile the orientation of the fiixed parabolic dunes with the present wind regime. They suggest formation by dominant westerlies.

(3) Regular narrow longitudinal dunes. These are well developed on the various sub-Rapanui surfaces near Castlecliff in the Westmere dune complex. They are all fixed, and no active dunes of this or the preceding types occur. Narrow longitudinal dunes have been interpreted as due to downward growth from some extremely localized source, as "wind shadow lee dunes" (Melton, p. 133) or as "tongues extending landward from a foredune" (Cotton, 1942, p. 109). Melton believes that "longitudinal dunes are the most sensitive of all dunes to change of wind direction" and "cannot develop the extremely elongate form . . . if the effective wind varies in direction more than 1° or 2°" (*loc. cit.*). It is unlikely that such constant winds can have operated at Wanganui; the dunes there, too, are improbably "wind shadow lee dunes," and their association with and gradation into hairpin-shaped parabolic dunes inclines the writer to the opinion that the two types are closely related in manner of formation. There is a distinct similarity between the "elongate blow-out" and "windrift" dunes illustrated by Melton and the forms at Wanganui. Melton considers these to be deflation forms developed under the influence of moderate and strong winds of constant direction, the wind direction being the direction in which the apex points.

For larger-scale desert phenomena the "sand ridges" of Australia (Maddigan, 1936) and the seif dunes of North Africa (Bagnold, 1941) definite relations between prevailing wind direction and dune direction have been shown. Bagnold (p. 234) puts forward the hypothesis that cross winds of shorter duration but stronger intensity than the prevailing winds (with which the dune ridges are roughly parallel) are necessary for the formation of longitudinal dunes. There are many differences, including size and cross section (lack of "slip faces"), between such large-scale phenomena and the longitudinal dunes at Wanganui, and it seems significant that their elongation is in no sense the resultant of the two strong wind directions at Wanganui, whereas the active dunes (in the Okehu and Nukumaru complexes) and the "seif dunes" of Bagnold are elongated parallel to such a resultant direction.

* The wind rose for all winds shows a dominance of light northerlies, but the rose for strong winds (over force 7) shows that westerlies and southerlies are of far greater importance in influencing dune form. The wind information is based on data for Wanganui, but frequencies are so similar to those at Patea that it may be fairly assumed that conditions at intermediate points on the coast are the same.

(4) Deflated dune areas. These are the result of the attack by wind, perhaps at quite a late date, of fixed dunes. Where any form can be seen in the deflated areas, it is of longitudinal ridges oriented in a general east-west direction, or of parabolic ridges similar to, but generally smaller than, those still existing landward of the active belts, which seem to have received the bulk of their sand from the deflated areas to windward. The sand of such exhumed dune skeletons is loamy and coherent, much stained with organic matter, and penetrated by decaying roots of herbaceous plants.

There is thus a difference between the orientation of the contemporary active dunes, which move north-eastward under the influence of both westerly and southerly winds, and that of the fixed dunes of previous dune cycles, which appear to have been formed by dominant westerlies, with no important southerly influence. Two alternative hypotheses to explain this anomaly may be advanced:—

(*a*) The older fixed dunes north-west of Wanganui may have been formed during a climatic episode in which strong southerlies were less important in determining dune orientation than they are at present. Melton (1940), from study of the orientation of several dune series, has reached interesting conclusions on the changes in the prevailing winds during the past fifteen thousand years in the Southern High Plains of North America. His conclusions are based on differences in the direction of sand movement in parabolic blow-out dunes and windrifts in dune series of different ages. These differences are comparable to those found for the Wanganui area. The active dunes of the Wanganui area are possibly less than a hundred years old and due to the activities of rabbits and stock in this period, but information on this point is lacking. Pharazyn quotes that remains of a Maori pa "were visible till lately (1869) . . . near the Okehu Stream. This, though half a mile from the sea, is now nothing but a vast sandhill" (Pharazyn, 1869, p. 159). The fixed longitudinal (west-east) dunes at Castlecliff overlie a terrace of the Wanganui River which was aggraded by the pumice alluvium of the geologically Recent Taupo Shower.

(*b*) From discussions with Squadron Leader C Palmer, Meteorological Office, I gather that any change in wind frequencies of the magnitude suggested by the dune orientations is unlikely to have occurred without leaving other abundant evidence, and that a change of cosmic nature can hardly be invoked. It is perhaps significant that the anomalous dunes are all capable of formation as deflation-forms, while the north-eastward-advancing active dunes are accretion-forms. It is thus possible to explain the anomaly as the response of these two categories of dune to different wind strengths and directions in a wind regime the same as that operating to-day.

There is as yet insufficient information available to determine whether either of the hypotheses advanced is valid.

THE MANUFACTURE OF GAUGES AND PRECISION TOOLS

PART II

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Summary

The concluding part of this article deals with the production of a variety of precision tools and components that have presented unusual features in design or in manufacture.

A short description of the training of staff and the routing and processing of work through the various shops is given, together with average production costs for such work.

INTRODUCTION

IN Part I of this article the necessity for precision work in the manufacture and measurement of tools and gauges was discussed at some length and a few isolated examples were given illustrating special methods introduced in the manufacture of gauges.

The same degree of precision is required in the tools responsible for the dimensions and form of the finished part, and in the jigs or holding fixtures that position it while machining is taking place.

The heat treatment of a tool is an all-important phase of the work, as hardness, toughness, and a minimum dimensional change during the process are all necessitated.

As mentioned in the earlier part of this article, space forbids a comprehensive treatment of the many and varied types of tools manufactured under wartime necessity, but, as with gauges, a few examples which have presented unusual features in either design or manufacture have been selected as being of general interest.

THE PRODUCTION OF SOME SPECIAL TOOLS AND COMPONENTS

The Manufacture of Precision Chasers for Die-heads and Collapsible Taps

For the quantity production of threaded components, especially on capstan, turret, and automatic lathes, the well-known solid-tap and split-die are usually replaced by the collapsing-tap and the self-opening die-head. When threading parts for interchangeable assembly, the cutting chasers for these tools require to be produced to close tolerances not only in their general dimensions, so that the chasers will fit standard heads, but more particularly in their thread form and dimensions. It will be appreciated that there must be a certain amount of slack, or fit allowance, between chasers and die-head to allow them to trip open at the end of the threading cycle, which makes the tool inherently less accurate than its solid counterpart, the die-nut or button die.

In making chasers, therefore, closer tolerances must be observed than in making commercial taps or dies. When, in addition, the chasers are to be used on munitions production, such as fuse parts or ordnance work, they become a job of high precision, comparable with limit screw-gauges. This entails the use of comprehensive fixtures for the initial milling and turning operations, and in some cases for the grinding of the threaded portion after the chaser has been hardened, so that pitch variation may be avoided.

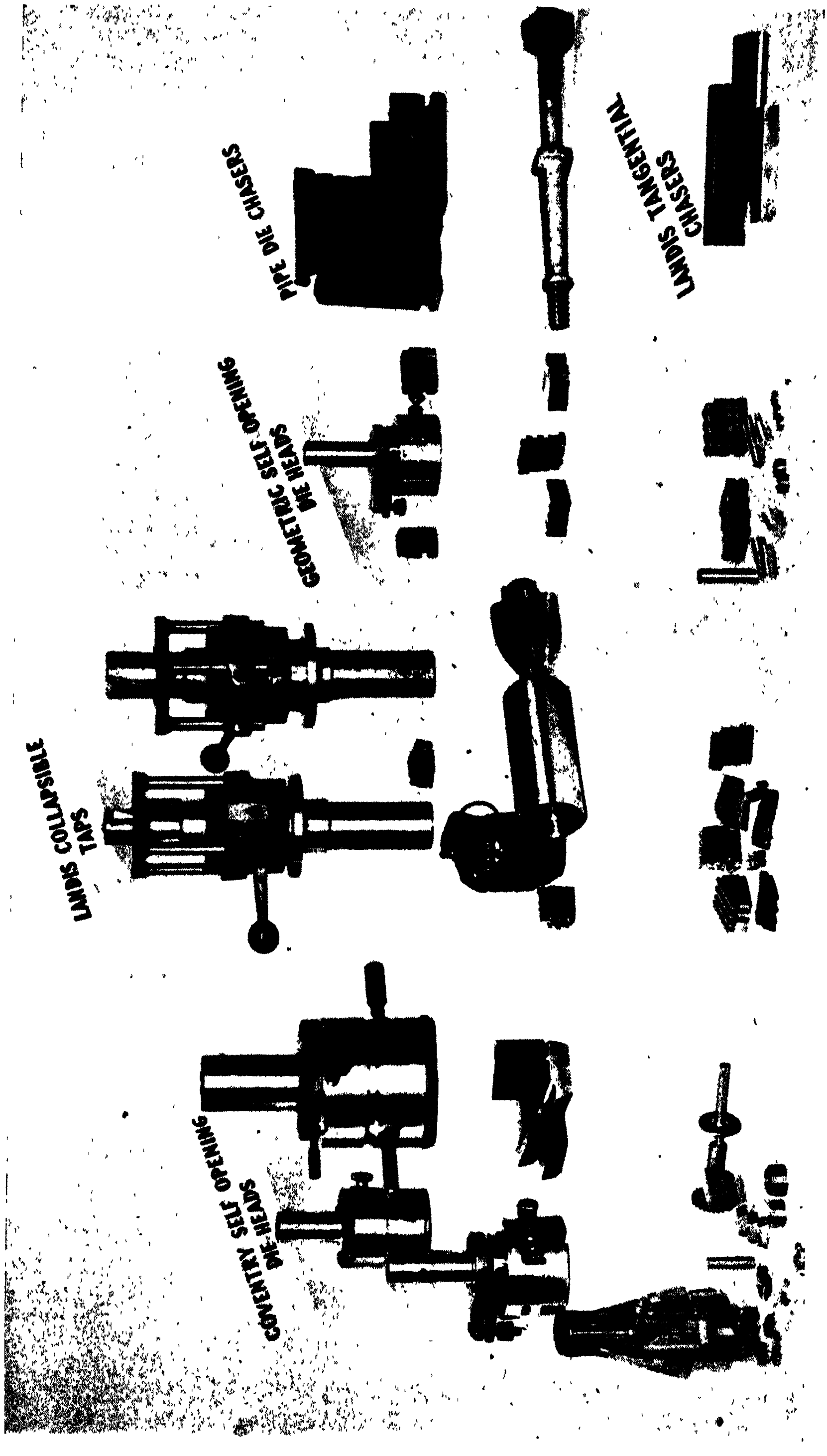

FIG. 1.—Precision chasers, die-heads and taps, and threaded components they produce.

Figure 1 shows a selection of these chasers which have been produced in recent months, together with the die-heads or taps in which they are used, and a selection of threaded work produced by the assembled tool.

Chasers in a wide variety of types and sizes have been produced, in batches varying from one set to fifty sets. The following types, however, form the bulk of our requirements: -

Landis collapsible tap—left hand and right hand.
Coventry die-head, $\frac{1}{2}$ in., $\frac{3}{4}$ in., 1 in., $1\frac{1}{4}$ in., 2 in. head.
Geometric die-head, $\frac{1}{2}$ in., $\frac{3}{4}$ in., 1 in. head.
Lanco and Landis tangential-chasers.

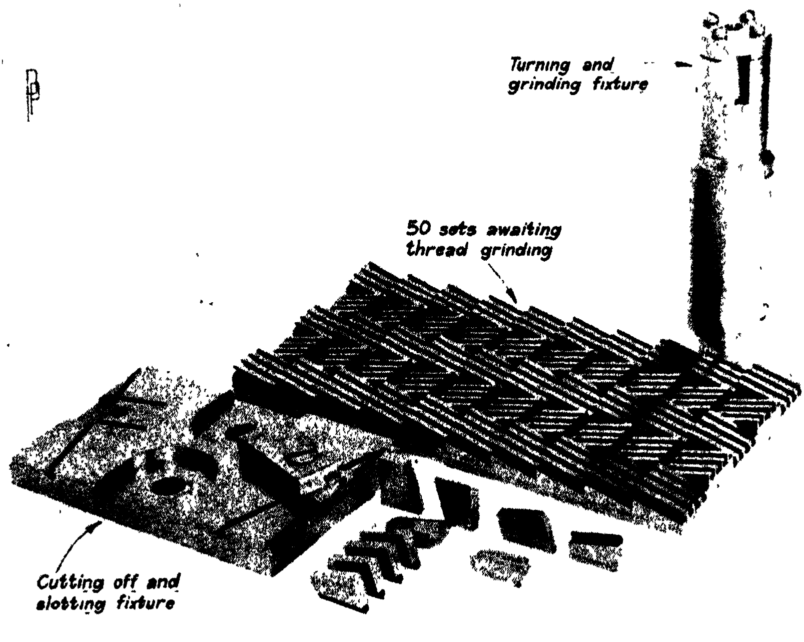

FIG. 2.—Fixtures for Landis tap-chasers and a group of completed chasers.

Landis Collapsible Tap-chasers. -This problem was complicated by the manufacture in New Zealand under wartime pressure of a number of Landis-type left-hand taps. In order to obtain satisfactory performance, these taps were remade by the Dominion Physical Laboratory. They required a chaser of slightly larger dimension than the Landis standard, having the throw-out groove on the opposite face. This entailed two sets of machining fixtures, and a subsidiary centre-piece for grinding, but no other alteration in process was necessitated.

A group of fifty sets of these chasers is shown in Fig 2, together with the milling fixture and the turning and grinding mandrel. The knock-out grooves can be seen on the chasers in the foreground, and it will be noticed that both types are represented there.

The steel used for the chasers was a standard 18 per cent. tungsten high-speed steel, using a 1 in. $\times$ $\frac{5}{16}$ in. flat section, which is first shaped and surface-ground to 0·980 in. $\times$ 0·252 in. in 12 in. lengths. These lengths were

milled in the angle fixture shown to make the chaser blank. A second operation in the same fixture forms the knock-out groove, and the blanks were then grouped in sets of four and stamped.

They were then heat-treated in a salt bath furnace at 1,230°–1,250° c., quenched in oil to room temperature, and given a double secondary hardening treatment in a nitrate-nitrite salt bath heated by immersed electrodes to 580° c. A hardness of about 62°–63° on the Rockwell c. scale was aimed at, as chipping trouble had been experienced with harder chasers when tapping this particular component—the pressed steel body of the 2 in. mortar bomb.

A mandrel simulating the Landis cone-head was used for grinding, and the chasers, after being surface-ground to width and length to fit the slots in this mandrel, were cylindrically ground to 0·010 in. above the major diameter, when the head was set in half-way position. The mandrel was then transferred to the thread-grinder and the threads ground from the solid, using the relieving attachment to give approximately 0·005 in. of form relief.

After thread-grinding, the chasers were given the necessary taper lead and spiral point on a tool and cutter grinder while still in the mandrel, and were then tested in a standard head on from five to ten bomb bodies to check for sizing, thread form, cutting action, tracking, and chipping of chaser. Upwards of two hundred and fifty sets of these chasers have been produced.

In the munitions plants these chasers were used in a Ward 2A Capstan lathe to tap twenty threads per inch, left hand, on a nominal diameter of 1·775 in., with a tolerance on diameter of 0·007 in. The component was difficult material to tap, being a pressed-steel body of fairly light section and variable hardness. An average of 9,000 parts per set of chasers was obtained, with some sets giving upwards of 35,000 parts.

Chasers for the Coventry Self-opening Die-head.—These chasers have been made both by the thread-milling and the thread-grinding process, depending on the accuracy desired. The milled chasers were produced in simple fixtures, the blank being first cut off to length in a milling-machine, and the throw-out slot milled or turned, depending on the type of chaser. Using a ground-thread multi-tooth milling cutter, the thread was milled in batches.

Most collapsible dies have four chasers to a set, these being located at 90° to each other. The position of the thread on No. 2 chaser was one-quarter of a pitch ahead of No. 1, and so on with No. 3 and No. 4, so that all chasers "track" on a true helix. In order to effect this, the batch of No. 1 chasers was first thread milled and the chasers marked "1." The milling-machine table cross-feed was then moved one-quarter of a pitch and a batch of No. 2 chasers milled and marked. A further quarter pitch indexed No. 3 batch, and a similar movement accounted for No. 4. Figures 3 and 4 show the fixtures and tools for this method.

The chasers were then heat-treated, finish ground on the locating faces, and sharpened.

Milled chasers have certain disadvantages—surface decarburization in heat treatment, particularly if "66" substitute high-speed steel is used, shortens the chaser life and makes it difficult to hold tolerances without resetting, and dimensional change and distortion in hardening causes pitch errors.

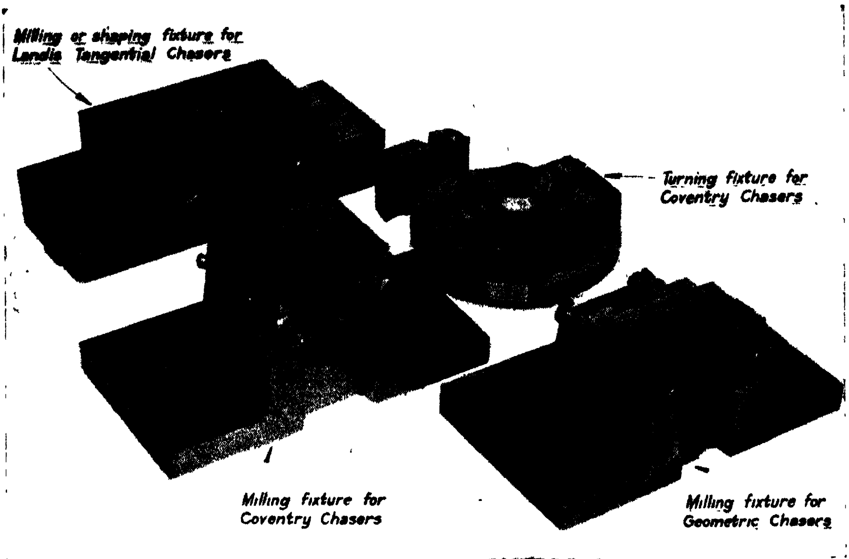

FIG. 3.—A group of milling and turning fixtures.

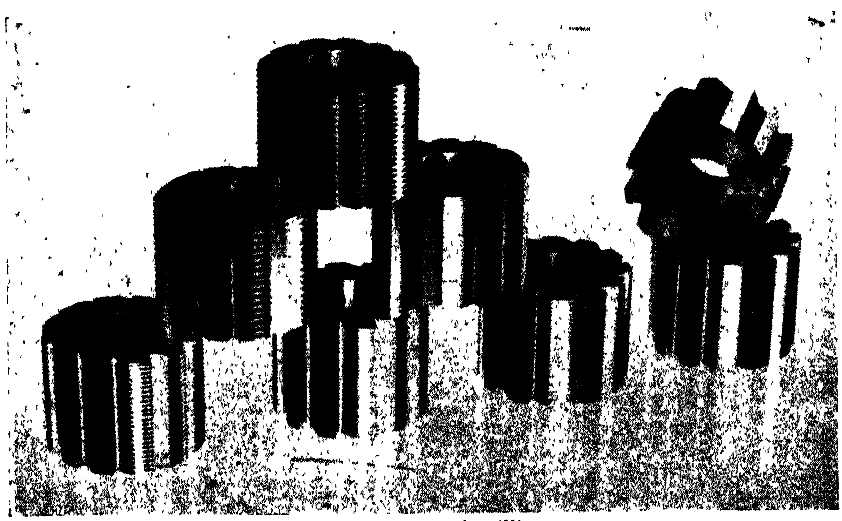

FIG. 4.—Ground-thread milling-cutters.

Precision chasers were thread-ground after hardening—in overseas production plants, special machines are available for this process. In order to take advantage of this refinement a special fixture was designed for use

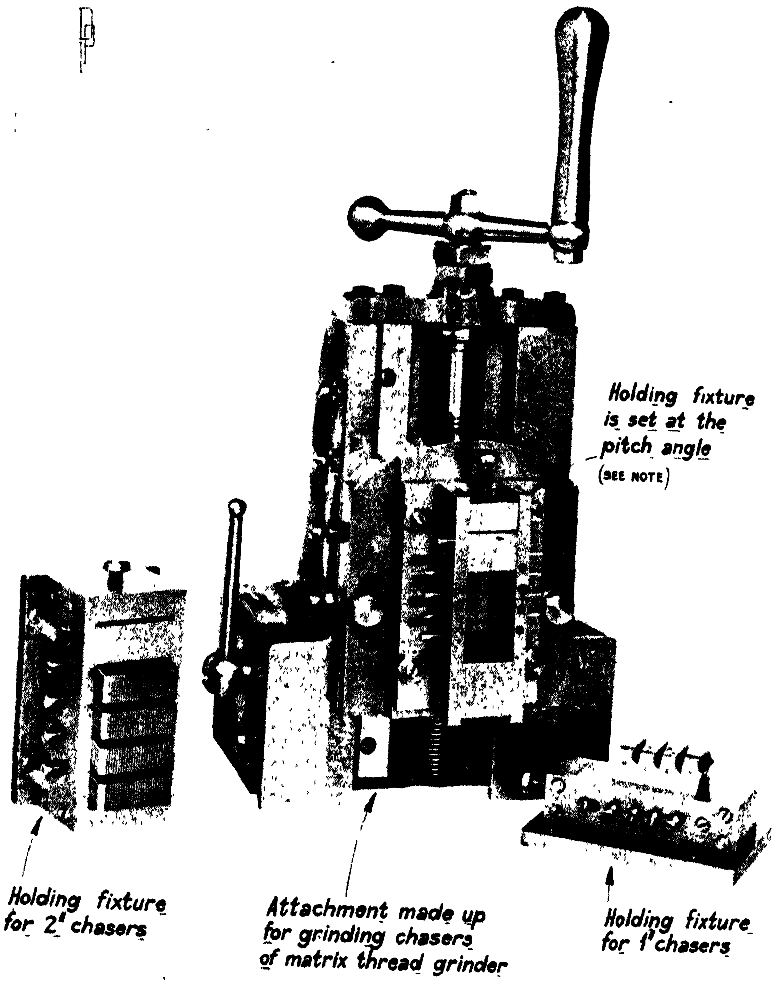

FIG. 5.—Chaser grinder attachment before motorization.

on the "Matrix" multi-rib thread-grinder. This fixture in its original form is shown in Fig. 5. The chasers were held in sets of four in a locating-box and were moved past the thread-profiled grinding-wheel by means of a double-start lead-screw, hand operated.

Separate locating-boxes were made for each size and type of chaser, the chasers themselves being located in sets of four from their bottom surfaces by means of ground rollers. The locating fixture was itself accurately positioned on the grinding slide by means of a sine-bar before the attachment was placed in position on the thread-grinder, as this fixture has to be set at the "*pitch-angle*" so that a set of four chasers would be ground the correct quarter-pitch apart. This angle will be the angle whose tangent is: pitch of thread divided by four times the chaser thickness; and although this will generally not correspond with the helix angle of the work to be cut by the chasers, they are designed with sufficient relief to avoid interference, except in extreme cases.

When interference is likely to occur, the chasers could be set in the same fixture at the *helix* angle and ground as described in the milling process above, *e.g.*—

(*a*) Grind batch (in this case, four, as this was the maximum capacity of the locating-box) of chasers No. 1.
(*b*) Index lead-screw quarter pitch and grind four chasers No. 2.
(*c*) Index lead-screw quarter pitch and grind four chasers No. 3.
(*d*) Index lead-screw quarter pitch and grind four chasers No. 4.

A multiple ribbed-wheel of the full width of the chaser was used, where possible, dressed to the thread profile with a diamond-dresser or a crushing-roll; but if the width of the chaser necessitated it, two or more cuts would be made, indexing between cuts by means of the thread-grinder lead-screw or by matching with the microscope.

Although a considerable quantity of work was successfully done with this attachment, two disadvantages soon become obvious. The first of these was the fatigue and monotony to the machine operator when producing a quantity of these chasers, especially if a number of light cuts were necessary. More serious was the "burning" of the work due to the low rate of traverse across the wheel. In order to overcome both of these troubles, the attachment was motorized, as shown in Fig. 6. A small single-phase $\frac{1}{20}$ h.p. motor was used, driving open and crossed leather belts. A simple dog-clutch engaged either motion, and this was actuated by two stops at the extremes of the stroke. Considerable improvement in finish resulted, and production times were substantially reduced, as the operator could set the machine in operation and occupy his time with marking, checking, and measuring while the grinding was in progress.

Landis Tangential-chasers.—These were handled singly in a special fixture used in conjunction with the above equipment and set at zero helix angle. Special thread-forms, such as double and treble start Acme form, Cordeaux form, and modified square thread form have been produced by this method to close pitch tolerances, and this accuracy is reflected in the final product, whether it be sluice-valve spindles, lead screws, or insulator pins.

The Production of Form-ground Milling-cutters

Certain profiled parts of the 2 in. trench mortar having tolerances in the neighbourhood of 0·001 in. to 0·002 in. necessitated form milling-cutters having an element accuracy in some cases as close as 0·00025 in. As it will be obvious that a lathe-relieved milling-cutter could not be produced within these tolerances, a method of relief grinding the hardened blank had to be evolved. Having had considerable success with the production of thread-gauges and thread-tools of difficult form, such as the Cordeaux and knuckle threads, it was decided to try the crushing-roll principle once again.

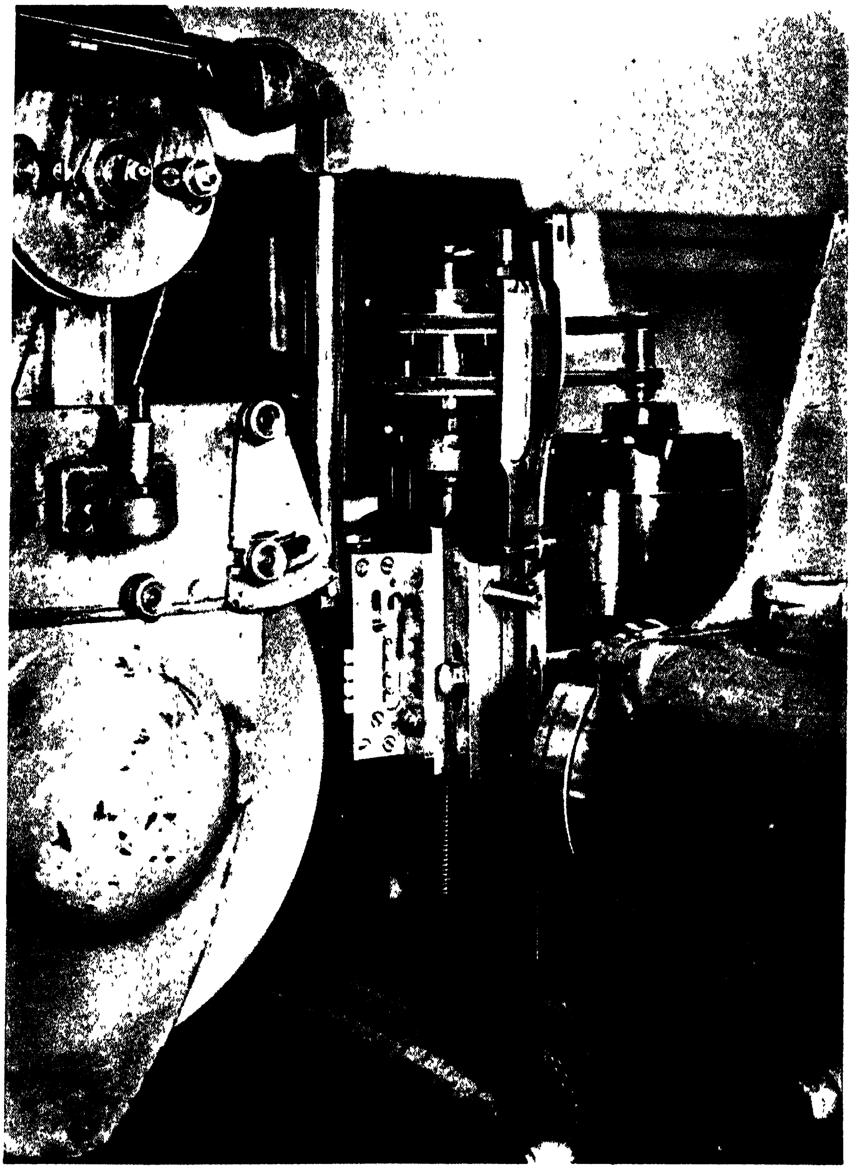

FIG. 6.—Thread-grinding attachment on matrix machine after motorization.

A tool was made up by hand to the required form and checked by inspection under a shadow profile projector in comparison with a form diagram fifty times actual size. From this a crushing roll of about 3 in. diameter was profiled. This was then diagonally gashed with $\frac{1}{32}$ in. slots and hardened to about 64 Rockwell c. Using a slow wheel speed and a copious flow of coolant, this form was transferred to a 220K thread-grinding wheel by crushing. The milling-cutter blanks of high-speed steel were then precut to the approximate profile, gashed, and hardened to 63–64 Rockwell c. After hardening, the cutters had their bores ground and lapped to fit a mandrel and were mounted singly in the thread-grinder, setting the relieving train to relieve ten flutes, with maximum relief. Grinding was then proceeded with until the whole of the cutter face cleaned up. The cutters were face ground, sharpened, and engraved as is normal procedure.

The maximum amount of relief possible with this machine was 0·058 in. and although this was satisfactory for most forms using light feeds, cutters having half-round forms were apt to have insufficient side clearance. To overcome this a crushing attachment has been made to fit the Cincinnati tool and cutter grinders, and this, in combination with a multi-flute relieving attachment, also recently constructed in our tool-room, will allow of a much larger relief being obtained. There is therefore no limit to the type of cutter that can be form-ground, and it is found that the cost of producing these cutters compares favourably with those produced on a form-relieving lathe. In addition to this, surface decarburization in hardening does not affect the final cutter, and added dimensional accuracy is ensured.

Figures 7 and 8 show examples of actual cutters produced, one of the formed crushing-rolls, and the component for which the cutters were needed.

The Design and Manufacture of Broaches to broach Keyways for British Standard Square Keys

In the normal design for a keyway broach there will be a definite number of teeth at a certain definite pitch, depending on the total depth of cut to be made. This means that the overall length of the broach is fixed within fairly close limits—for the three sizes ($\frac{1}{4}$ in., $\frac{5}{16}$ in., and $\frac{3}{8}$ in.) the length varies between 24 in. and 30 in., including the broach shank. A difficulty immediately arises in handling work of this length in the normal tool-room and heat-treatment shop, and ways and means of lessening the effective broach length are therefore advisable. It is not possible to reduce the number of teeth without increasing the cut-per-tooth beyond a safe figure, nor can the tooth pitch be decreased without reducing the chip space, unless quite thin work is to be broached.

The following methods suggested themselves :—

(*a*) The use of a series of two or more shorter broaches.
(*b*) The use of a single short broach with an inserted packing piece during the second cut.
(*c*) The use of two or more short broaches mounted in a holder or arbor.

As the first two methods mentioned above necessitate two or more cuts with resultant increase of cutting time, it was decided to design a series of broaches to method (*c*).

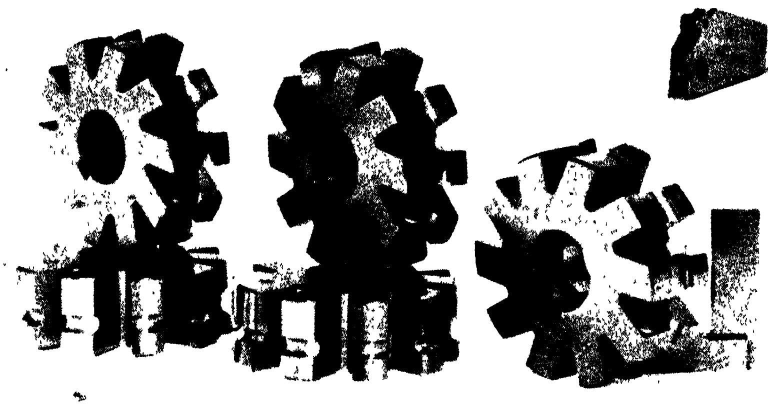

FIG. 7.—Ground form relieved milling-cutters, and part produced by them.

FIG. 8.—Ground form relieved cutters, with crushing roll used.

So that they should be more universal, the broaches were designed to be interchangeable in the arbors—*e.g.*, the $1\frac{1}{4}$ in. arbor would carry either the $\frac{5}{16}$ in. broach or the $\frac{3}{8}$ in. broach. As these broaches were to be used for cutting standard keyways in cast-iron and steel pulleys, the arbors were machined from a bar of S.D. 50 axle steel to a dimension slightly less than the shaft-hole diameter.

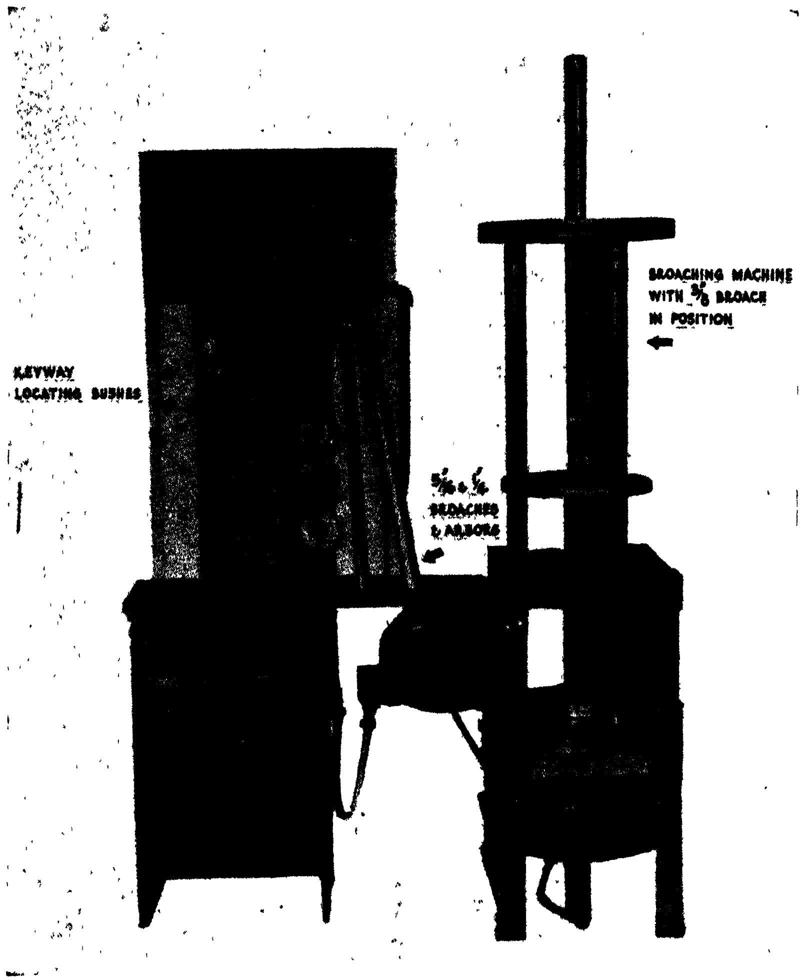

FIG. 9.—Layout of screw-broaching machine, showing $\frac{3}{8}$-in. broach in position.

As will be seen from Fig. 9, the broach sections were rectangular, and two such sections fitted into a milled groove in the arbor. The original broaches were made from "Keewatin" tool steel, hardened and tempered to 64° Rockwell c., while later tools were produced from 18 per cent. tungsten high-speed steel.

A screw-operated broach-puller was used, driven by a 1 h.p. electric motor, and the broach-arbor slotted eccentrically to bring the line of action nearer the centre of the teeth, rather than the centre of the arbor. This is also clearly shown in Fig. 9.

Little difficulty was experienced in machining the bottom of the broach slot in the arbor, this being milled in relation to the bottom surface of the arbor at such a taper that the correct rise per tooth was obtained with a parallel broach section. The final sizing-teeth, four in number, were afterwards ground parallel to the bottom surface of the arbor. The broach sections were normalized both before and after the tooth-gashing operation, and consequently remained moderately straight in the hardening process. After hardening, the lower face was surface ground and used as a locating face for the tooth-grinding. Final sharpening was performed with the broach sections mounted and clamped in their arbor.

In operation, the broaches performed most satisfactorily. A minor alteration was found advisable after the broaches had been in use for some while. This was the substitution of Allen socket-head set-screws for the slotted set-screws originally used in the arbor to prevent possible lifting of the first broach section when entering the cut.

The Manufacture of Hardened and Ground Film Sprockets

Although scarcely a precision tool, this component presents another interesting example of form grinding, using the crushing-roll method for obtaining the correct wheel profile. A shortage of Ernemann-type intermittent sprockets for the standard 35 mm. motion-picture projector became apparent early in 1943, and the laboratory was asked to make a sample sprocket. As the accuracy specified was high—$\pm 0{\cdot}75$ minutes on angle and $\pm 0{\cdot}0002$ in. on diameters—it was decided to harden and then grind to finished form so that distortion in heat treatment would not affect the accuracy of the finished sprocket.

The sprocket was first machined from an oil-hardening "non-shrink" tool steel such as "Kite" or "Keewatin," leaving 0·010 in. to 0·012 in. for grinding-allowance. The sprocket teeth were gashed, leaving slightly more than this for finish grinding. The sprocket was then oil-quenched from 800° C., and finally tempered in an air recirculation furnace to about 62 Rockwell C. to relieve stresses and possible further distortion. The central bore was first ground and lapped to fit a mandrel, on which subsequent work was done between centres.

In order to provide a ground, involute profile on the sprocket teeth, a crushing roller was profiled by optical means (see earlier report on form-ground milling-cutters) and after hardening was used to profile a 220K9 aluminium oxide grinding-wheel on the Cincinnati tool and cutter grinder. The sprocket was mounted on its mandrel in the Cincinnati dividing-head and each tooth-flank form-ground separately, using a wheel surface speed of 4,000 ft. per minute, and no coolant. The dividing-head was covered to protect it from abrasive dust during the dry grinding process. Cylindrical grinding of the exterior surfaces then completed the sprocket.

This sample socket, under test in an Auckland theatre, ran through more that half a million feet of film with no noticeable signs of tooth wear, or "hooking." Its performance for steadiness and quietness was superior to several makes of imported sprockets, due, no doubt, to the ground and polished finish on the tooth profile.

Figure 10 shows the sample sprocket together with its form-crushing roll and a fixture which mounts this roll so that it may be used to profile the grinding-wheel. This fixture was carried on the work table of the tool and cutter grinder, the forming process being effected by turning the grinding-wheel and spindle by hand when in contact with the crushing roll. The roll revolved freely, its helical gashes having a wedging action on the wheel, which gradually became formed to a profile complementary to that of the crushing roll. It will be noticed that the roll in position in the fixture is one of Whitworth form, used in profiling a wide thread-grinding wheel for thread-mill work.

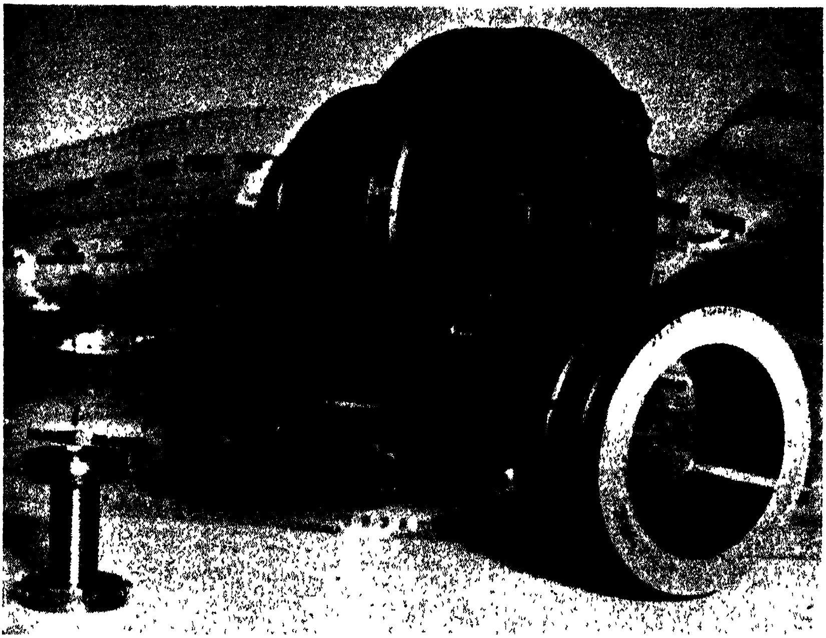

FIG. 10.—Form ground 35 mm. film sprocket and crushing roll for forming the wheel.

THE TRAINING OF STAFF FOR PRECISION WORK

It is not possible in the space available to discuss at length the methods adopted in the training of staff, this being the subject of a separate report. Suffice it to say that key men were obtained from non-essential industries and certain men given a short period of training in Australia in the more specialized side of munitions-tool making.

Both unskilled men and unskilled women were employed, after short periods of basic training at the Wellington Technical College. The period of their training was timed to coincide with the completion of the new Dominion Physical Laboratory at Lower Hutt, and here the machine-shop and grinding-room were so arranged that trainees could be employed on the " one man, one machine " principle.

Although the use of girls for such work was an innovation for this country, excellent results were obtained on widely varying types of work.

Routing and Scheduling of Work

As will be realized from the foregoing paragraphs, the tool-room staff comprised a large proportion of semi-skilled, or, more correctly, partly trained, workers, and some production system based on the "one man, one machine" principle was necessary. Gauge and tool work, even on a large scale, consists of small batches. It is better compared with jobbing work than with mass-production work, and so some modification of the usual production controls seemed desirable.

In the early stages partial controls were instituted as the expansion of the tool-room made them necessary, and a complete production control system was established when the new tool-room was established.

Gantt, one of the pioneers in production control, has specified as follows the three main aims of production control:—

(1) Are all the machines running? If not, why not?
(2) Are they doing first priority work first? If not, why not?
(3) Are they doing it as rapidly as they should? If not, why not?

This entails the following controls:—

(*a*) The work must be broken up into machine processes, so that trainees may operate on the "one man, one machine" principle, and then routed through the shop from process to process.
(*b*) A priority sheet for orders must be maintained and first priority work handled first.
(*c*) Some system of machine loading, coupled with an idle machine record, is necessary.
(*d*) Work scheduling, or anaylsis of process times, should be carried out, to see that the men are doing their jobs in the shortest time, as reflecting the best possible method.
(*e*) A progress record system is desirable, so that daily and weekly progress in an order may be followed.
(*f*) Satisfactory time and material booking must be arranged, so that costing may be facilitated.

Although all the above controls are necessary in some degree, it is desirable that the system installed should be operated by the minimum of staff. To secure this, we adopted what is called the bin, or rack, system.

It is not possible, in the space of this article, to describe in detail the the procedure of routing an order through the tool-room; nor, for the same reason, is it possible to illustrate all the necessary forms and charts. A brief description of such features of the system as depart from conventional practice will be given.

Suppose, for example, that an order for six special milling-cutters was received, for delivery to a munitions contractor. This order originates from the office of the Controller of Munitions, who would indicate the relative urgency of these tools by naming a position on his priority sheet. Copies of this sheet were received weekly, so that work could be planned to ensure that machines did first priority work first. On receipt of this order the necessary clerical entries were made and an internal shop order despatched, via the tool-room foreman, to the store, where six slabs of high-speed steel of the size required were cut off and put in a shallow box, together with the blueprint of the finished tool. The shop foreman affixed a coloured card to the box which showed the machining processes that would be involved in making the tool, and their order.

In each of the machine-shops there was a rack capable of holding some fifty of these boxes, in eight to ten columns (see Fig. 11). Each column represents a particular process, such as " tool-room lathes " (process No. 4), " milling " (process No. 7), or " thread-grinding " (process No. 16). The box from the store went into this rack under the first process listed on the card, and on a level representing its priority. An operator, on finishing a job, passed the box to the sub-foreman, who, after inspection, replaced it

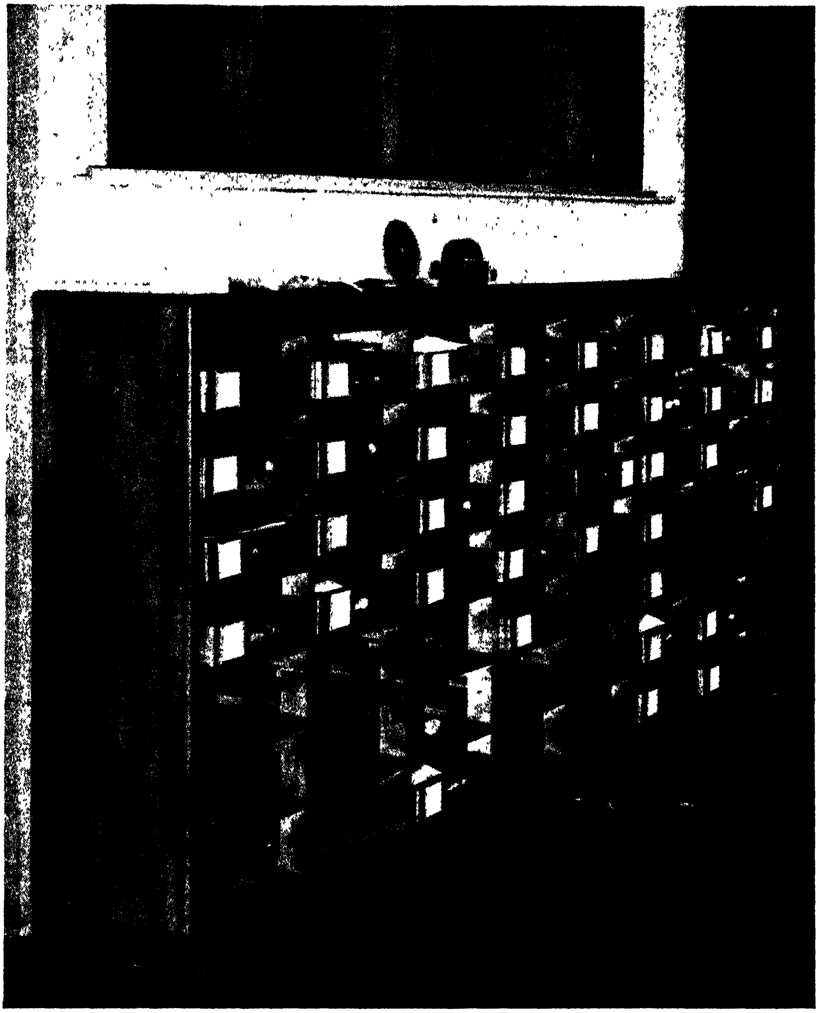

FIG. 11.

in the column representing the next process. The top box in the operator's column was passed out as his next job, and so on. Looking at the rack, the foreman could see how much work he had ahead of each machine group—his lathes, his shaper, and his mills. He could ensure that the racks were kept full and could plan a balance of work. This gave a measure of control over : " *Are all the machines running?* " and also " *Is first priority work being done first?* "

An "*idle machine record*" was also kept, being graphed on the Gantt method from the daily time books, and this was made to serve the dual purpose of checking on idle time and of showing the proportion of work done for munitions plants and for industry. This latter record was required for differential costing purposes.

This leaves the last of Gantt's queries, "*Are they doing it as rapidly as they should?*" Before this question can be considered we must know how long a particular process should take—in other words, we must have a time study of how long is taken by the average workman. All work must therefore be planned and estimated.

The foreman had already split up his job into processes, or machine groups, when loading the racks, and it was therefore a comparatively simple matter for him to provide estimated times as well. The first time a particular job was undertaken, this estimate was little better than a guess, but by judicious study, records, and checking on past work, this guess became a reliable estimate, and this estimated time was entered on a special card as a red line of appropriate length. The workman recorded his time daily, and as his time was entered for costing purposes a clerk drew a black line on the estimate card to represent the actual time taken.

This check was very valuable when employing trainees, as it showed how their training was progressing, and when studied alongside the final inspection sheets gave a fair impression of their relative efficiency. An added advantage was that the foreman was compelled to plan his work in detail, and difficulties must be the subject of a conference of all parties concerned before tackling the job, rather than after mistakes had been made.

Estimating allowed us to increase our efficiency: it showed us whether shaping or milling was cheaper for a certain operation: it showed us which operators had been "cutting air," or letting their machines overrun their work piece; it gave us data by which we could closely predict the cost of some special tool to a customer, and keep an eye on the processes where this cost might have been exceeded; and it allowed us to revise our heat treatment and grinding allowances so that a bare minimum of material had to be removed in the final (and most expensive) processes.

These estimate cards were kept in a card index, being filed under job numbers. A double check on machine loading could be kept by heading the card as shown, and using Roneo type signals on the processes not completed. The totals of the signals in each row will give the total machine loading in that group.

Figure 12 shows a specimen of the estimate card, and also a section of the Gantt idle machine record, showing the differentiation between munitions work and other industrial work.

PRODUCTION COSTS

Owing to difficulty in assessing the capital value of certain lend-lease machines installed in the tool-room, the following figures are given in man-hours, which, however, will suffice for purposes of comparison.

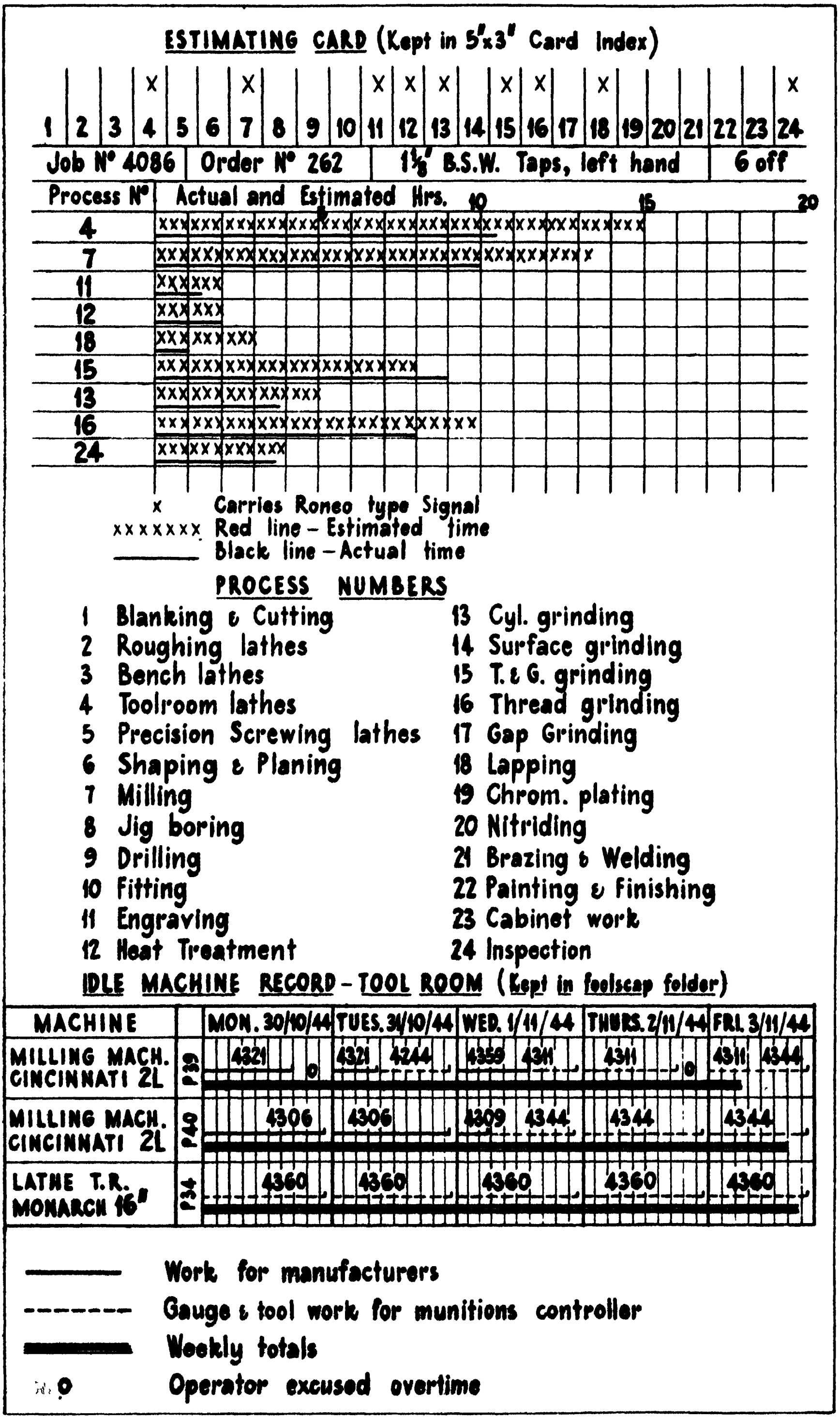
ESTIMATING CARD (Kept in 5"x3" Card Index)
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24
Job N° 4086
Order N° 262
1⅛" B.S.W. Taps, left hand
6 off
Process N°
Actual and Estimated Hrs.
10
15
20
4
7
11
12
18
15
13
16
24
x Carries Roneo type Signal
xxxxxxx Red line - Estimated time
Black line - Actual time
PROCESS NUMBERS
1 Blanking & Cutting
2 Roughing lathes
3 Bench lathes
4 Toolroom lathes
5 Precision Screwing lathes
6 Shaping & Planing
7 Milling
8 Jig boring
9 Drilling
10 Fitting
11 Engraving
12 Heat Treatment
13 Cyl. grinding
14 Surface grinding
15 T. & G. grinding
16 Thread grinding
17 Gap Grinding
18 Lapping
19 Chrom. plating
20 Nitriding
21 Brazing & Welding
22 Painting & Finishing
23 Cabinet work
24 Inspection
IDLE MACHINE RECORD - TOOL ROOM (Kept in foolscap folder)
MACHINE
MON. 30/10/44
TUES. 31/10/44
WED. 1/11/44
THURS. 2/11/44
FRI. 3/11/44
MILLING MACH. CINCINNATI 2L
P39
4321
4321
4244
4359
4311
4311
4311
4344
MILLING MACH. CINCINNATI 2L
P40
4306
4306
4309
4344
4344
4344
LATHE T.R. MONARCH 16"
P34
4360
4360
4360
4360
4360
Work for manufacturers
Gauge & tool work for munitions controller
Weekly totals
Operator excused overtime

FIG. 12.

These figures are the averages of a considerable number of separate batches, varying between six off and eighteen off. They have been grouped according to types and tolerances :—

	Man-hours per Unit.
Gap-gauges ; combined go-not-go ; tolerance on gauge 0·0001–0·0004 in. ..	6·5
Gap-gauges ; ditto ; tolerance on gauge 0·0004–0·001 in.	3·5
Gap-gauges ; ditto ; tolerance on gauge 0·001–0·003 in.	2·0
Plain plug-gauges ; taper-lock type ; tolerances 0·0001–0·0005 in.	4·5
Plain plug-gauges ; ditto ; tolerance 0·0005–0·002 in.	2·5
Screw plug-gauges, taper lock ; ¼ in. to 1 in. major diameter. B.S.S. tolerances	6·0
Screw plug-gauges ; ditto ; 1 in. to 2 in. major diameter. B.S.S. tolerances ..	7·5
Screw ring-gauges ; 1 in. to 2 in. major diameter. B.S.S. tolerances ..	14·0
Conomatic machine-taps ; ½ in. to 1 in. major diameter, grade 1 ground thread	3·0
Coventry-type chasers ; ⅞ in. head ; per set	10·0
Landis tap-chasers for 1 775 in. diameter ; per set..	8·0

ACKNOWLEDGMENT

I would like to acknowledge at this juncture the co-operation and suggestions of Mr. N. A. Mackay, who in his position as project supervisor of tools and gauges with the Munitions Controller instituted priority sheets, scheduling cards, and the gauge recall system at that office so that a reasonable forecast of future requirements could be made.

THERMAL CONDUCTIVITY MEASUREMENTS ON SOME NEW ZEALAND HOUSES

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Summary

An outline is given of a simple method for determining the thermal conductivity of walls, ceilings, and floors of New Zealand houses. The method is shown to be an adaptation of more elaborate overseas methods, involves very little equipment and labour, and can be applied conveniently to completed houses without damage. Results show conformity with overseas figures and with values obtained by calculation using accepted overseas formulæ. A discussion on the significance of the results is included.

IN the course of a general investigation into the effect of atmospheric conditions on the incidence and growth of mould on walls and ceilings, it appeared that the conditions which were of most importance were those closer to the inner wall and ceiling surfaces. As these are to a large extent determined by the thermal conductivity of the wall sections, particularly outside walls, it was desirable to obtain values for the conductivities of various types of wall structures and to relate them to other data.

It should be realized that a complete survey of all types of houses built in New Zealand was not contemplated. The aim was rather to ascertain that overseas formulæ for calculated values were reliable under New Zealand conditions and in particular to confirm certain special indications arising from previous work on house construction and materials. Probably the most important of these was the result of measuring air movement in the wall cavities of houses, which had suggested that "brick-veneer" houses (of which the cavity is ventilated for drying purposes) would show high

conductivity or transmittance. Likewise, in view of the fact that tiled roofs allow free flow of air above the ceiling, it was expected that large losses would occur through the ceiling, especially if it were of plaster-board, a material of fairly high thermal conductivity. The results showed satisfactory confirmation in each case.

There is, of course, an abundance of data on the thermal properties of building-materials such as are used in New Zealand, and well-tried methods are known whereby the conductivities of built-up sections can be calculated from such data. There are also available results of experiments in which sample sections of walls are made up and tested in a special hot-box apparatus. The principle of this apparatus, which is used in America(1) and in Canada(2), is shown in Fig. 1. The British equivalent(3) of this method is shown diagramatically in Fig. 2.

There are, however, two facts that made the results of these tests insufficient for our purpose. These were—

(1) The tests were made on test sections only and not on completely erected walls.

(2) There was no evidence that methods and workmanship were exactly equivalent to those used in New Zealand.

With these facts in mind, a relatively simple method was evolved for measuring approximately and quickly the conducting properties of walls of completed houses of different types. The quantity measured was the overall transmittance U = number of B.T.U.s transmitted per square foot per °F. per hour.

METHOD

The method is essentially the same as the American method shown in Fig. 1. The heated cabinet was placed against the inner wall of the house, and the room was controlled at the same temperature as the cabinet and therefore acted as a guard-ring, while the outside atmosphere acted as the cold chamber (see Fig. 3).

The limitations of the method are at once apparent, one of the chief difficulties being that the experiment depends on the outside weather conditions. Previous experience had shown, however, that reasonably steady temperatures frequently occur over the major part of the night, and, in fact, there was no difficulty from this point of view throughout the tests. Other factors of which no account was taken were outside temperature gradients from ground-level upwards and wind velocities. It was considered, however, that the results would give a general comparison under actual conditions, and the results were found to vary much less than was expected.

In the following description of the apparatus it should be borne in mind that the tests were made at short notice and with equipment that was to hand for immediate use. The results showed that the method is quite useful for the type of measurement required, and with the experience gained a greatly improved set-up could be designed for permanent use.

HEATED CABINET

The cabinet consisted of an outer plywood box strengthened with 2 in. by 1 in. wood battens, and lined with 4 in. of Kanex insulating-material. The leading edge was fitted with a gasket of rubber tubing to provide an airtight seal when pressed against the wall. (A layer of felt would serve, but may not be airtight, and the area could not be computed accurately.) The area enclosed by the rubber gasket was 12·25 square feet.

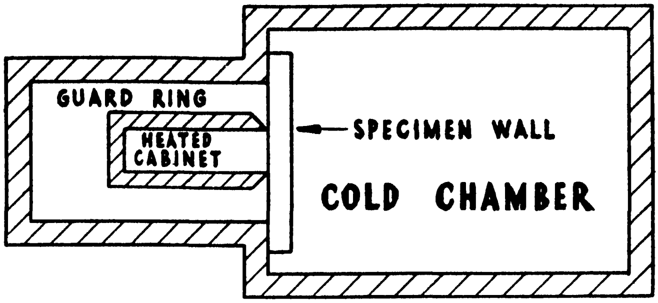

FIG. 1.—American method.

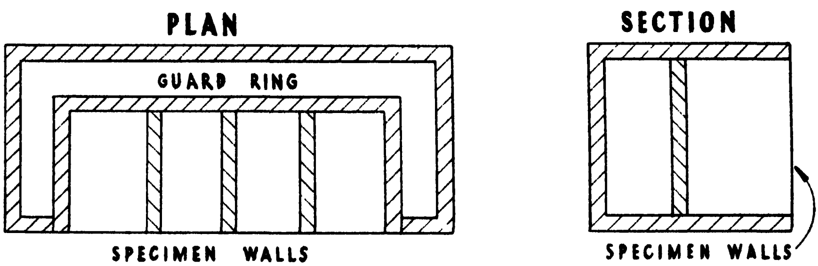

FIG. 2.—British method.

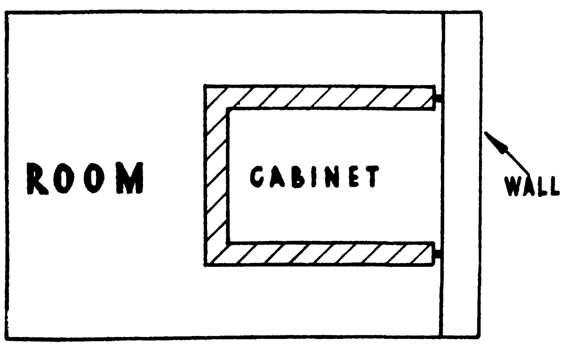

FIG. 3.—New Zealand method.

The cabinet was heated by two 15 w. bulbs, with provision for switching in a third bulb if necessary. The bulbs were placed on the bottom and two sides at different distances from the front. The air was stirred by an 8 in. fan ($\frac{1}{20}$ h.p. motor) directed slightly towards the back wall of the cabinet. Differential thermocouples placed in the cabinet indicated negligible temperature differences throughout the cabinet.

The cabinet was pressed firmly against the wall to be measured by means of beams wedged against the opposite wall.

The temperature of the cabinet was controlled by an air thermostat, and the method of measuring the watts input was such that a very small differential was undesirable. On the other hand, this made the recording of cabinet temperature more difficult until the thermocouple was lagged to smooth out the larger variations. A similar procedure was adopted in the case of the room thermocouples.

The differential in the cabinet was $+ 1°$ F. and in the room $+ 2°$ F.

RECORDING WATTMETER

As in ordinary thermal conductivity measurements, it was necessary to know the heat input to the cabinet during a period of stable outside temperature. The recorder used was merely an "on-off" recorder controlled from the cabinet thermostat. From this record it was possible to integrate the time for which the heating-lamps were on and so obtain the total heat input. The watts supplied by the motor and fan were measured separately. A continuously recording wattmeter would obviously be preferable.

TEMPERATURE-RECORDING

Four temperatures were recorded continuously by means of two string recording galvanometers viz., the cabinet temperature, outside temperature, room temperature, and attic temperature (this refers to the intermediate temperature above the ceiling, within the wall cavity, or beneath the floor; it has no direct bearing on the calculation of overall transmittance U). The sensitivity of the recorders was approximately 0·9 m.v. for full-scale deflection and it was necessary to use several couples in series, according to the temperature differences to be measured and the length of the couples. The wire used was 26 S.W.G. copper and constantan. In the case of outside temperatures, for example, it was necessary to have at least 1 ft. of wire projecting outside the room to avoid conduction along the wires. The cabinet temperature was measured approximately 4 in. from the wall, the outside temperature 8 ft. above ground, and the room and attic temperatures near the cabinet. The outside couple was shielded from rain to avoid "wet-dry" effects.

The reference junction for the thermocouple measurements was a special hot-box controlled by a mercury-toluene regulator. This was kept accurately at 75° F. and the cabinet and room at a mean temperature of 70° F. The air in the room was circulated by a 12 in. fan ($\frac{1}{3}$ h.p. motor), this being more than sufficient to obtain even temperature throughout the room. Maximum and minimum thermometers served as a check on the control of the room.

Various sizes of rooms were used, and a 2 kw. heater was found sufficient to control smaller rooms. In larger rooms—*e.g.*, 14 ft. by 12 ft.—a 1 kw. heater was used continuously in addition to the controlled 2 kw. A second pen on the same drum recorder was used to indicate the total input to the room over the test period. Large openings such as fireplaces were covered to prevent undue losses.

ACCURACY OF METHOD

The accuracy of the method could scarcely be stated as better than ± 5 per cent. for the mean of a number of results. The agreement with calculated results is therefore reassuring, although some assumptions are also involved in the calculations.

It is interesting to note that the method can be applied to completed houses without damage to the structure or to wall finishes such as papering, &c.

RESULTS

Measurements were made on outer and inner walls, ceilings, and floors of four houses of different types. In three of the houses the walls were lined with Gibraltar board and the ceilings were of Pinex. In the other house the walls were lined with fibrous plaster-board, the ceiling being of the same material. All floors were of 1 in. tongued and grooved wood.

The quantity determined was the overall transmittance U defined as the number of British thermal units transmitted through 1 square foot of wall area per degree (Fahrenheit) difference in temperature between the air inside and outside of the wall, and given by the following equation:

$$U = \frac{Q}{A} \cdot \frac{1}{T_2 - T_1} \cdot \frac{1}{t}$$

where U = overall transmittance, in B.T.U.s sq. ft./°F./hr.
Q = total input in B.T.U.s, in time t.
T_1 = outside air temperature, in °F.
T_2 = cabinet temperature, in °F.
t = time of test period, in hours.
A = area of cabinet presented to the wall, in square feet.

The following table of results shows the experimental results and calculated values for each house. All calculations are made assuming wall cavities to be airtight, and in some cases thermal conductivity values are assumed for the materials used where no actual figures are available.

House No.	Construction: Outside	Construction: Inside.	Part measured.	Mean Value of U.	Calculated Value
1	Brick ..	Gibraltar board	Ceiling (Pinex)	0·40	0·37
			Outer wall ..	0·54	0·40
			Floor ..	0·37	0·37
2	Poelite..	Gibraltar board	Outer wall ..	0·41	0·38
			Floor ..	0·38	0·37
			*Floor (corrected)	0·40	0·37
3	Wood ..	Gibraltar board	Outer wall ..	0·41	0·32
			Inner wall ..	0·31	0·34
4	Brick ..	Fibrous plaster	Outer wall ..	0·50	0·41
			Ceiling (plaster)	0·59	0·72

* The values of U for the floor of this house were found to vary much more widely than any other values. It was also observed that the temperature below the floor varied considerably in its relation to the outside temperature. Values of U were therefore calculated using the temperature below the floor as the "outside" temperature, and consistent values were then obtained. The "corrected value" shown above is the mean of these results.

Houses Nos. 1 to 3 were new houses situated together in Newcombe Street, Waddington (near Naenae). House No. 4 was situated in Bell Road, Lower Hutt, and was completed approximately five years ago.

DISCUSSION OF RESULTS

Apart from the significance of the actual values of U, some interesting points arise from the comparison of experimental and calculated values :—

(1) Brick outer walls are very much more conducting than theoretical values would indicate. As stated previously, this may be caused by ventilation of the cavity, which is known to be high in this type of wall. The calculated value of U for a sheet of Gibraltar board alone is approximately 0·60.

(2) A similar difference of a smaller degree occurs in the case of the outer wooden walls. This at first suggested that the weather-boarding is not airtight and allows air to circulate between the wood and building-paper. If the wood were removed entirely, the value of U for a wall of plaster air-space paper would be approximately 0·40, which tends to confirm the above suggestion. it was later ascertained, however, that some ventilation at least is provided intentionally during the construction, so that the difference in thermal conductivity may be attributed to either cause. It is worthy of note that, according to the literature available, wherever timber is used overseas it is common to employ a thin outer sheathing for weather protection and a 1 in. sheathing with overlapped joints, with building-paper between. The addition of 1 in. thickness of timber in this fashion to the above wall should give a value of U = 0·29.

(3) There is substantial agreement in all other cases. Calculations for ceilings are rather uncertain. It should be noted, also, that figures for ceilings are really those for roof and ceiling combined, including attic space.

These facts indicate that any type of house construction which for any reason permits the circulation of cold air within the wall cavity is open to serious question on the grounds of poor thermal conductivity. As a further check, the temperature within the cavity (above the ceiling, beneath the floor, &c.) was recorded in each case to study its relation to the outer temperature. As would be expected, those walls which were well ventilated were of high conductivity and the cavity temperature was close to the outside temperature. In effect, the circulation of air removes the insulating effect of the outer wall, and the only protection is that supplied by the inner lining. Where the walls were airtight, the cavity temperature was intermediate between inner and outer temperatures and the conductivity was lower and agreed more closely with theoretical values. This factor of air movement in the cavity, then, is one of great importance, and a good deal of work has been done on this subject separately.

In the cases of houses having airtight walls such as Poelite, building-paper, plaster, the values are such as would be expected from our knowledge of the materials used. Improvement can only be effected by the addition of insulating-material in the wall, and this matter will be brought out later.

Before discussing ways of reducing the overall transmittance, some examples will be given of the effect of U on the temperature of rooms and the cost of heating them. Figure 4 shows the temperature attained by a

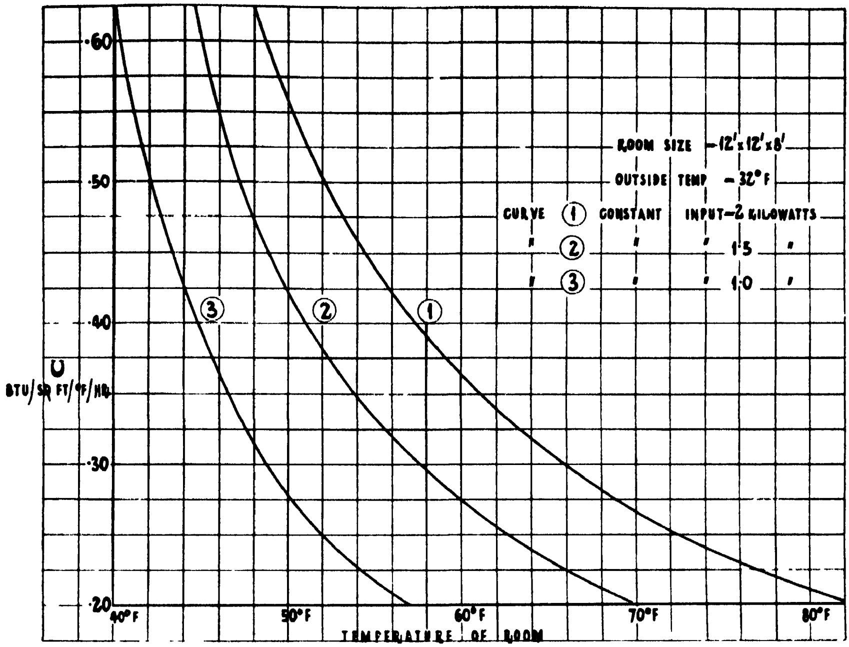
·60
·50
·40
·30
·20
U
BTU/SQ FT/°F/HR
40°F
50°F
60°F
70°F
80°F
TEMPERATURE OF ROOM
ROOM SIZE — 12'x12'x8'
OUTSIDE TEMP — 32°F
CURVE 1 CONSTANT INPUT—2 KILOWATTS
" 2 " " 1·5 "
" 3 " " 1·0 "
3
2
1

FIG. 4.

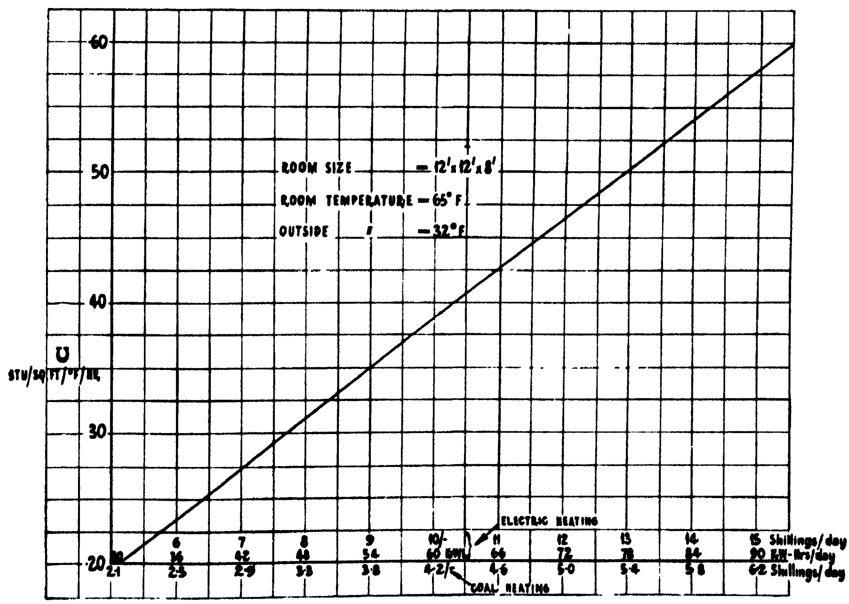
60
50
40
30
20
U
BTU/SQ FT/°F/HR
ROOM SIZE = 12'x12'x8'
ROOM TEMPERATURE — 65° F
OUTSIDE " — 32°F
ELECTRIC HEATING
COAL HEATING
15 Shillings/day
90 KW-hrs/day
6·2 Shillings/day

FIG. 5

heated room 12 ft. by 12 ft. by 8 ft. having values of U from 0·15 to 0·65 for an outside temperature of 32° F. The mean values for the four rooms tested are given below without making allowance for windows, &c. :—

House No.	Overall Value of U.
1	0·47
2	0·40
3	0·40
4	0·45

Figure 5 shows the relation between values of U and the relative amount of power used to maintain a 12 ft. by 12 ft. by 8 ft. room at a steady temperature of 65° F. with outside temperature 32° F. On the basis of a charge of 2d. per unit (kWh.), the cost is also given. As an approximate comparison, the cost of heating by coal is given, on the basis of 11,000 B.T.U.s per pound of coal burned in a grate of 20 per cent. efficiency and at a cost of 5s. per hundredweight.

REMEDIES

There are three general ways in which the conductivity of houses may be reduced :—

(*a*) Improved airtightness of the cavity, roof, &c.
(*b*) The use of materials of low conductivity where possible.
(*c*) The addition of insulating-material between the walls.

(*a*) The first of these has been discussed, and it need only be restated that any factors which cause or require ventilation are open to question. The question of lining roofs or covering ceiling joists with an airtight layer is worthy of consideration.

(*b*) The second can be discussed only in general terms, as the choice of materials is affected by such matters as availability, mechanical properties, cost, and expediency. The possible saving of fuel power and cost should, however, be considered along with these other properties. Another factor which is of lesser importance is the surface finish of the wall surfaces, especially outer walls. Table I shows relative values of surface conductance for different materials for a mean temperature of 20° F. and an air velocity of 15 m.p.h. :—

TABLE I

Surface.	Surface Conductance (F.)
Glass	5·1
White paint on pine	5·1
Smooth plaster	5·5
Clear pine	5·7
Concrete	6·8
Brick and rough plaster ..	7·2
Stucco	8·9

(c) The addition of insulating-material is a subject that calls for some comment, since the effect of this may not be appreciated. It is known that the thermal resistance (inverse of conductivity) of an air space increases very rapidly with the size of space until the size is about 0·2 in., when the resistivity approaches 1—*i.e.*, conductivity or transmittance $= \frac{1}{\text{resistance}} = 1$. Thus the resistance of five spaces each equal to 0·2 in. is about five times that of a single 1 in. air space.

Most insulating-materials make use of this principle, and by providing a large number of small air spaces they possess high thermal resistance. When a layer of material of this sort is included in a wall, the overall resistance is increased and the conductivity reduced. The following table shows the improvement effected by adding different thicknesses of material having a conductivity K = 0·30 B.T.U./hr./sq. ft./° F./in. thickness (Pinex board has a value approximately 0·33) :—

Original Value of U.	Values of U with Insulation (½ in. to 3 in.).				
	½ in	1 in.	1·5 in	2 in	3 in.
0·2	0·15	0·12	0·10	0·087	0·067
0·3	0·20	0·15	0·12	0·10	0·076
0·4	0·24	0·17	0·13	0·11	0·081
0·5	0·27	0·19	0·14	0·115	0·084
0·6	0·30	0·20	0·15	0·12	0·087

From these figures the most important conclusion is that walls which are of high conductivity show greatest proportional improvement with added insulation and therefore greatest proportional saving in heating cost. Likewise, for any wall the proportional improvement is greater for the first ½ in. of insulation added than for any subsequent ½ in. In general terms this means that an initial gain in insulating properties of walls is simple and cheap and can effect great savings in heating costs. Beyond a certain stage the ratio of cost to saving becomes uneconomical, except for special applications.

OVERSEAS STANDARDS

There is little information on the values of U which are considered adequate in different countries. British opinion as expressed by the Ministries of Health and Works is as follows :—

(1) *External Walls.*—U not greater than 0·3, with values as low as 0·15 recommended.

(2) *Ground Floors.*—U not greater than 0·3, and recommended down to 0·15.

(3) *Roofs.*—Not above 0·3, and values of 0·2 recommended. (Tiles are commonly laid on felt and battens, and plaster ceilings insulated above.)

Canadian officers regard the following figures as typical of Canadian houses, *without insulation* :—

(1) Exterior walls : U = 0·25.
(2) Ceiling and roof combined : U = 0·31.
(3) Ceiling alone : U = 0·69.
(4) Roof alone : U = 0·46.
(5) Glass (single) : U = 1·13.
(6) Doors : U = 0·52.

Such a house, they state, would never be used. It is invariably supplied with insulation in the walls and ceilings, and fitted with double-glazed windows and weather-strips surrounding doors and windows.

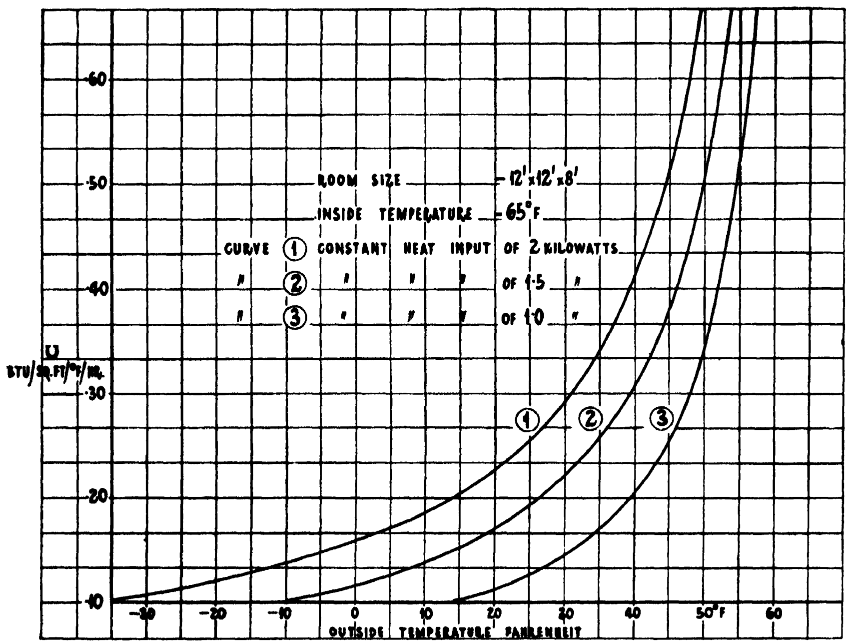

FIG. 6.

The value of U required is largely determined by the outside temperatures likely to be encountered, and the graph of Fig. 6 shows the value of U required if a room 12 ft. by 12 ft. by 8 ft. is to be maintained at 65° F. for various outside temperatures. From this, some idea of the value of U for New Zealand conditions can be obtained.

ACKNOWLEDGMENTS

This work is part of a general programme of housing research at the Dominion Physical Laboratory, and acknowledgment is due to the Director, Dr. E. R. Cooper, for permission to publish the results separately. We wish also to acknowledge the assistance of Dr. L. Bastings, who suggested the method and supplied information on air-movement in wall cavities and other data used in the calculations.

REFERENCES

(1) ROWLEY, F. B., and ALGEN, A. B. (1937): *Eng. Exp. Sta., Univ. of Minnesota, Bull. 12.*
(2) BABBIT, J. D. (1939) *Can. J. Res., 17 (Sect. A)*, p. 164.
(3) DUFTON, A. F. (1942): *J. Inst. of Heating & Vent. Engrs., 10*, pp. 65–83.

Additional Literature

NEWCOMBE, S. F. (1944): *J. Roy. Inst. Brit. Arch., Aug.* 253.
Ministry of Fuel & Power, London: *Fuel Efficiency Bulletin.* 12.
Inst. of Heat & Vent. Engrs., London (1942): "Computation of Heat Requirements for Buildings."
Housing Manual (1944), London (Ministries of Health & Works.)
BABBITT, J. D. (1940): *The Eng. J.*, January.

EQUIPMENT FOR X-RAY CRYSTALLOGRAPHY

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Summary

A demountable continuously evacuated x-ray tube with interchangeable targets is described. An outline of the full wave rectified circuit is given, together with a brief description of the pumping system. The voltage is variable from 0–70 kv. The current rating is 15 milliamps.

To meet the needs of an apparatus for use in applications of x-ray crystallographic analysis and microradiography(1), a demountable x-ray tube with evacuating and electrical equipment has been constructed at the above laboratory.

THE TUBE

Since microradiography requires as many different wave lengths as possible to be readily available, a number of target metals for the anode (or anticathode) must be provided. Three interchangeable anodes (Fig. 1 (*g*)) were made. On the flat face of each were affixed the various target materials, (*d*). The first anode has "silver" soldered to it, copper, molybdenum, and silver; the second, cobalt, iron, and nickel; the third, chromium and two spare positions. The faces of the targets were ground flat, and the resulting thickness of the elements is about 0·025 in. Each anode has a male taper part which fits into a single female taper, (*f*), of the main body of the tube, (*e*). The tapers were ground after the fixing of the target materials to prevent distortion by heat.

The axis of the anode is displaced from the axis of the main body, (*e*), so that the latter axis passes through the centre of the target material. Rotation of the anode through 120° will bring another target metal into the line of the axis of the main body, and further rotation brings the remaining target metal into line. The tapers are sealed with high-vacuum grease (Apiezon M), and the rotation can be done without detriment to the degree of vacuum. Interchange of the anodes requires the pumps to be switched off, the oil condensation pump to be allowed to cool, and the change made. Re-establishment of the vacuum takes about fifteen minutes. The anodes are made of copper, with provision for internal water-cooling, (*h*).

The filament, (*k*), is supported by a brass tube, (*l*), which is held by clamps, (*o*), to the glass part, (*p*), of the main body of the tube. The filament lies at right angles to the axis of the tube and is bisected by it. Tungsten wire 0·225 mm. diameter spot-welded to short lengths of 1·5 mm. nickel wire is used for filaments. Several were made by a local electric-lamp manufacturer. In order to obtain a line focus along the axes of the windows, (*j*), it has been found necessary to orient the filament almost parallel to the planes of the windows. This is due probably to the relative displacement of the axes of the anode and the main body of the tube, producing an assymetrical field between the filament and anode.

The electrical connection to the filament is made as follows: short tungsten leads, (*a*), are sealed to the glass portion and are extended by copper wires, (*m*), the necessary distance inside the brass tube, (*l*). The joints are made by small brass connectors, (*n*). These facilitate the change of filaments should one burn out.

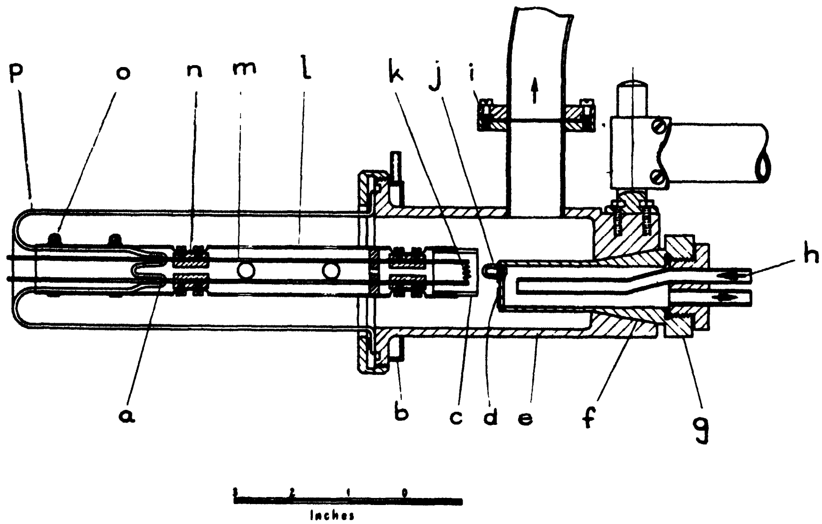

Fig. 1.—The tube.

The electrons are brought to a focus on the target metal by means of the focussing shield, (*c*), which is simply a copper tube threaded to its support, which may be screwed in and out until a line focus is achieved. Copper is used in preference to brass, since the zinc in the latter is volatilized by the heat radiated from the filament(2).

Two windows, (*j*), diametrically opposite one another, are slots 0·25 in. long and 0·078 in. wide covered with aluminium foil 0·001 in. thick cemented in place with Plicene cement. The aluminium will be replaced by beryllium when available.

The glass portion, (*p*), has a flange on it which has been lapped so that its plane surface is at right angles to the axis of the cylinder. This flange is fixed to a similar flange on the metal body, (*e*), using high-vacuum grease. A retaining-ring with rubber washer provides the necessary mechanical support. The joint is kept cool by the water-jacket, (*b*), underneath the metal flange. Without the water-cooling the radiation from the filament is sufficient to soften the grease very considerably and also soften the Plicene cement at the windows. A water-switch is incorporated in the electrical circuit so that if the water-supply should fail, the electricity is immediately cut off from all the apparatus except the backing-pump.

THE VACUUM PUMP

The pumping-system consists of an all-metal two-stage vertical oil condensation pump backed by a Megavac rotary vacuum pump. The condensation pump is made entirely of brass, with the inside components and the inside of the main barrel nickel-plated to prevent catalytic decomposition of the oil (Amoil S) by the brass(3). The connection from the pump to the tube is made by a short right-angle bend (1 in. diameter copper tube) of large radius of curvature. Attached to the copper tube by a tapered metal, Plicene - cement, glass seal is a glass discharge - tube. A Ford induction-coil connected across this tube gives a rough idea of the degree of vacuum. It has been found that if the tube is evacuated to such a degree that no discharge takes place, then the x-ray tube functions satisfactorily.

The copper tube is attached to the pumps and the x-ray tube, using flanged joints, (*i*), sealed with gaskets of Velumoid sheet ($\frac{1}{32}$ in. thick) painted each side with Glyptal lacquer. This type of joint may be made very quickly, and if the screws are tightened in a regular sequence the joint will be vacuum-tight.

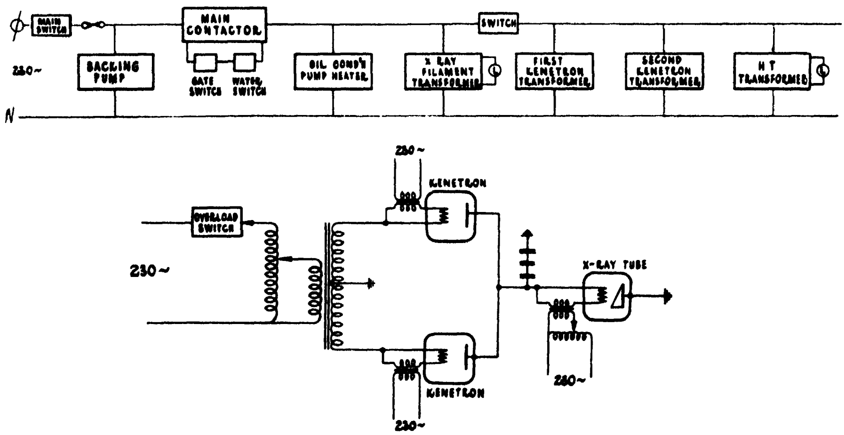

Fig. 2.—Circuit diagram (showing main switches only).

THE ELECTRICAL CIRCUIT

The anode of the tube is operated at earth potential to permit working in close proximity to the windows. The conventional diode full-wave rectifier circuit was modified to give Fig. 2, enabling the anode to be earthed. The diodes require separate filament transformers each with its secondary insulated from the primary winding by sufficient insulation to withstand the peak rectified voltage. Such transformers were made locally.

The only high-voltage condensers available were 0·5 μfd. 30 kv.p. oil-filled condensers. Three were connected in series, the two at the highest potential being provided with additional insulation to earth by mounting them on porcelain pedestals (see Fig. 3). The whole bank was connected across the tube to give a constant potential across it.

Kenetron (K R–3) diodes were used as the rectifiers and were hung by ½ in. diameter Idolite rods from the top of the cage which surrounds all of the high-voltage gear.

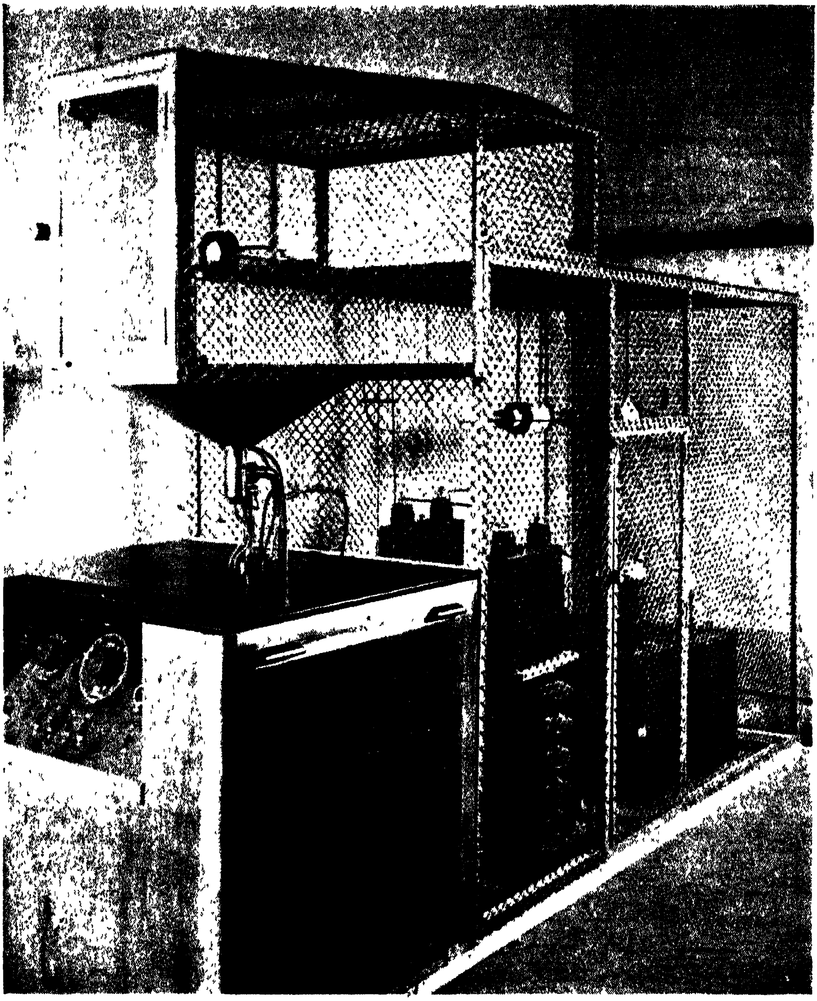

Fig. 3.—General view of equipment.

An attachment to the door of the cage carries an arm which drops on to the high-tension side of the condensers when the door is opened, discharging them to earth through a 6 megohm resistance. At the same time a gate switch cuts off all the electrical supply except that to the backing-pump.

The high-tension side of the circuit is connected up with ¼ in. diameter copper tubing. All bends are of radius greater than 3 in. The D.C. milliammeter is suspended from the cage by ½ in. diameter Idolite rod. All points of high tension are at least 12 in. from the nearest point of earth potential.

A spark gap with variable distance between the spheres(4) is used to measure the high-tension voltage across the tube.

OUTPUT

The voltage is continuously variable from 0 70 kv. The current rating is 20 milliamps. The current is limited by the capacity of the high-tension transformer, not by the heat dissipation at the target metal.

Powder photographs taken on a 10 cm. diameter camera with unfiltered copper radiation can be obtained in about thirty minutes.

REFERENCES

(1) MADDIGAN, S. E., and ZIMMERMAN, B. R. (1944): Microradiography—A New Metallurgical Tool. *Metals Technology Technical Publication No. 1683.*
(2) SMITH, C. J. (1929): *Rev. Sci. Ints.*, *VI*, p. 251.
(3) STRONG, J.: "Modern Physical Laboratory Practice." Blackie and Son, Ltd.
(4) Rules for the Measurement of Voltage with Sphere-gaps. *B.S.S. 358.*

VARIATIONS OF MONTHLY RAINFALL IN NEW ZEALAND

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Summary

A representative figure for the fluctuations of monthly rainfall in New Zealand is an average variation of 44 per cent. about the average of the month, but at Waimarama (Hawke's Bay) the January rainfall has a mean variability as high as 77 per cent., and Puysegur Point shows a variability of only 18 per cent. in its May rainfall. In the North Island the percentage variations are greatest in February and least in July. For the South Island as a whole September has the least and February the most variable rainfall, but about Canterbury the July rainfall is the most variable. The distribution of the variability over the country is shown in maps, on which the greater variability on the east coasts stands out conspicuously.

Monthly rainfall has an unsymmetrical distribution, occasional very wet months compensating for numerous months with moderately light falls. In a group of records with a variability of the order of 70 per cent. the rainfall mode (the most likely value) was found to be only 18 per cent. of the average and the median 74 per cent.—*i.e.*, half the rainfalls were below 74 per cent. of the average. The frequencies of occurrences of percentage rainfalls of different magnitudes arranged according to the degree of the variability are summarized in tabular form.

A typical station experiences more than six successive months with rainfall below average four times in thirty years and with rainfall above average about once. One of the most notable occurrences was the period of sixteen months from June, 1923, at Oamaru, when the rainfall was 49 per cent. below average. Cuvier Island had a run of fifteen wet months from March, 1916, with an aggregate rainfall 66 per cent. in excess of the average for the period.

There is evidence that there is a tendency towards persistence of type, the order of the effect being indicated by the average probability of a dry month; this is 54 per cent. if the past month was wet, but increasing to 59 per cent. if the past one was dry.

INTRODUCTION

THIS discussion is concerned with the nature of the variations of rainfall for a particular month from year to year. The variability of annual rainfall in New Zealand has been treated previously(1), and in a similar manner consideration will be directed to the mean monthly variability, defined as the mean departure, irrespective of sign, of the monthly totals from their average expressed as a percentage of the latter. Section I deals with the mean variability in its seasonal and geographical distribution over the Dominion, Section II with the frequency of occurrence of departures from average rainfall of various magnitude, and Section III with the persistence of months with rainfall above or below average.

I. MEAN VARIABILITY OF MONTHLY RAINFALL OVER NEW ZEALAND

Monthly rainfall records for the thirty years, 1911–40, from ninety-one stations—forty-seven in the North Island and forty-four in the South Island—were used as fundamental data. In several cases these records were completed by interpolating after comparisons have been made with two or more neighbouring stations with overlapping records. The average of the rainfall amounts was obtained for each of the twelve calendar months from the thirty years of records, and the mean of the thirty departures from average was determined as a percentage of the average rainfall. The general average for all months and all places is a variability of 44 per cent., but the variability differs with locality and season. For example, Waimarama, Hawke's Bay, was found to have a mean variability of 77 per cent. in January. At the other extreme, Puysegur Point has a mean variability of only 18 per cent. in May. In districts where the higher degree of variability prevails, a knowledge of average monthly rainfall(2) has a limited practical significance unless supplemented by information on the variability. Table I, containing a summary of the results in the form of averages for the stations in each Island, will indicate the general seasonal trend and the order of variability experienced.

TABLE I.—MEAN VARIABILITY OF MONTHLY RAINFALL PER CENT.

——	Jan.	Feb.	Mar.	Apr.	May.	Jun.	Jul.	Aug.	Sept	Oct.	Nov.	Dec.	Average.
Average for North Island stations	51	57	53	44	44	37	36	37	37	42	41	51	44
Average for South Island stations	44	52	47	45	46	43	49	43	42	44	38	46	45
Average for all stations	48	54	50	44	45	40	42	40	39	43	40	49	44

For the country as a whole, including the majority of the North Island stations and many southern stations, February is the month with most variable rainfall. All North Island places have the greatest variability in one of the months December to March. In the middle of the South Island the greatest variability occurs in or near July, which is the month when the North Island average is lowest. The average is least for the South Island as a whole in November and for the Dominion in September.

There is a tendency, more noticeable in the North Island, for the variability to have negative correlation with the average rainfall amount, in that wetter months have lower variability than those in the drier season.

The geographical distribution of mean variability is shown in the twelve maps constituting Fig. 1.

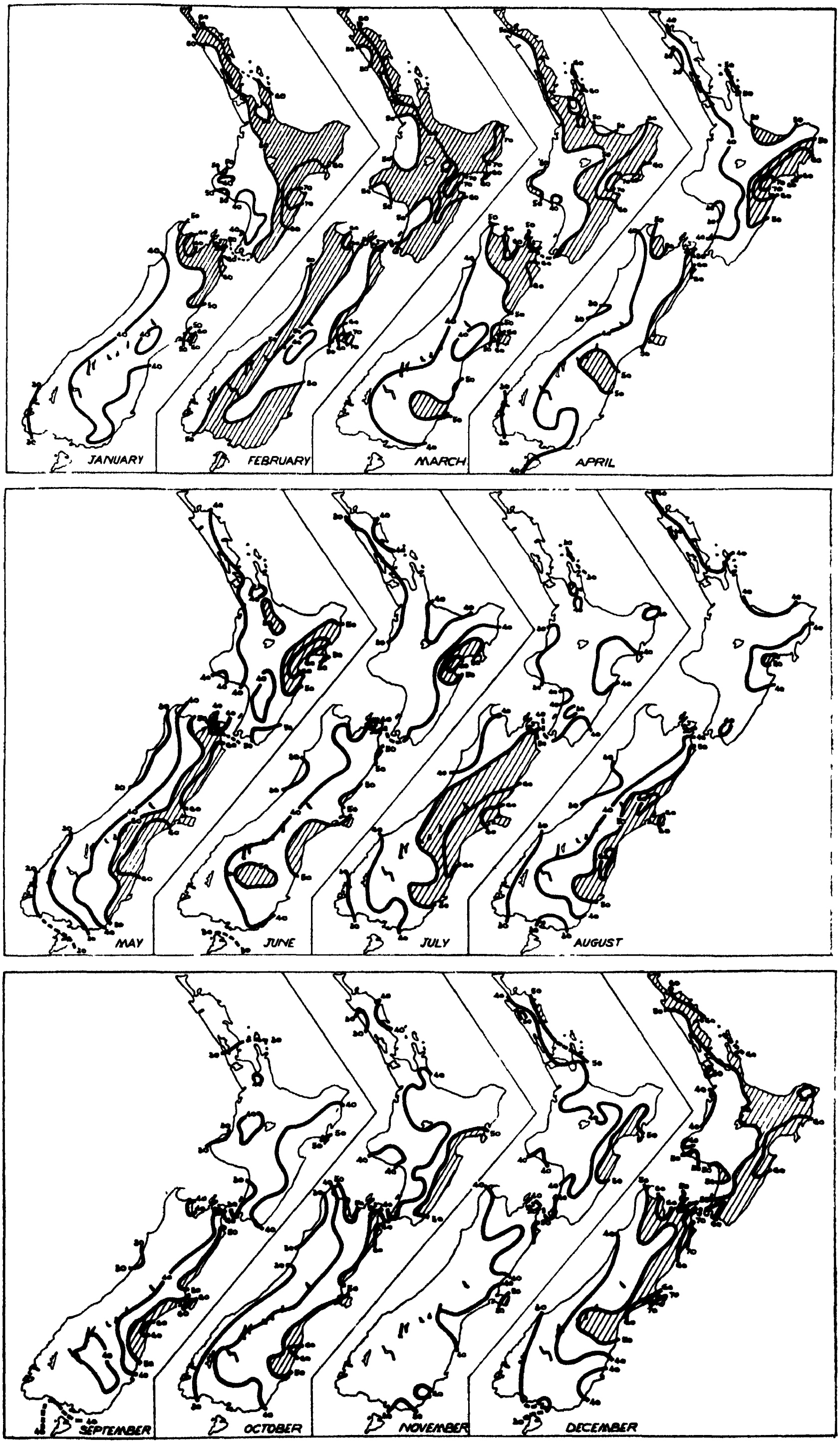

FIG. 1.—Mean variability of monthly rainfall (per cent.).

From December to March the areas of high variability are the more north-eastern portions of both islands, Hawke's Bay and Nelson. These months form the period when extra-tropical cyclones are most likely to affect this region, and the areas mentioned are those which may occasionally but irregularly receive very heavy rains, especially with winds from a north-east quadrant associated with such cyclones. During the next three months the east coast south of Gisborne has the most variable rainfall, and thereafter up to October it is the east coast of the South Island which figures most prominently. During that time of the year southerly or south-westerly conditions are most prevalent, but, as mentioned when considering annual rainfall variations(1), the amount of rain brought is erratic, being influenced considerably by the location of the centre of the depression and the precise direction of the wind. In November, variability is becoming comparatively more conspicuous again in the North Island.

Low variability is a very persistent feature south of Westport and Nugget Point. Most pressure troughs, whatever their detailed structure and the actual path of the main low pressure centres, contribute some precipitation to these areas, and, although the amounts vary, a month is sufficiently long a period for the total to be relatively constant. The general direction of the prevailing winds over the whole region is west to south-west, and other areas, such as the western side of the North Island, which are also exposed to these, have a fairly reliable rainfall, although with somewhat larger variations than in the west and south of the South Island.

II. FREQUENCY DISTRIBUTION OF MONTHLY RAINFALL

The mean variability of monthly rainfall, as discussed above, gives an indication of the relative extent of the departures of rainfall from the average for a certain month from year to year. A more concrete demonstration of the significance of the variability is given below in terms of the frequency of occurrence of departures of varying magnitudes. A selection was made of forty-six representative stations, twenty-three being fairly evenly spread over each Island, and their records were sorted into five groups by taking for each station those months for which the mean variability was centred about the values 30, 40, 50, 60, and 70 per cent. respectively. All the individual monthly rainfalls were expressed as percentages of the appropriate thirty-year averages, and these percentage rainfalls were divided into ranges of 10 per cent. and their frequencies counted.

These frequencies, as with most rainfall statistics, were distributed unsymmetrically about the average, for the low-rainfall side is limited at zero rainfall, whereas on the excess side falls which are several times the average are not uncommon.

The remainder of this section contains a fairly condensed account of the statistical treatment, and it is suggested that the general reader refer more especially to Fig. 2 and to Table III, which gives a summary of results obtained after irregularities in the original figures were smoothed out.

The frequency curve most suited to the data for each of the five variability groups was a Pearson curve of type I, this being an inverted bell-shaped curve with a base of limited range. It was clear from the data that each curve should start at zero rainfall, and if this starting-point is adopted as origin the equation can be expressed in the form

$$y = a\, x^{m}\, (b - x)^{n};$$

where x is the rainfall and a, b (the range), m and n are constants. With the origin so fixed, only the first three moments were required to

effect the curve fitting(3). The constants obtained from this process are set out in Table II, which shows also the average variability of each group derived both from the original figures and from the graduated statistics. The standard deviation σ (the root-mean-square deviation), the mode (which is the value of x corresponding to the maximum frequency), and the median (which is the value of x such that rainfall above and below it occurs with equal frequency) are included in this table. The unit taken for x here corresponds to 10 per cent. of average rainfall, and the values of σ, mode, median, and b refer to the same scale. It may be remarked that, although b represents the whole range of the frequency curve, values of y become negligible long before x approaches b.

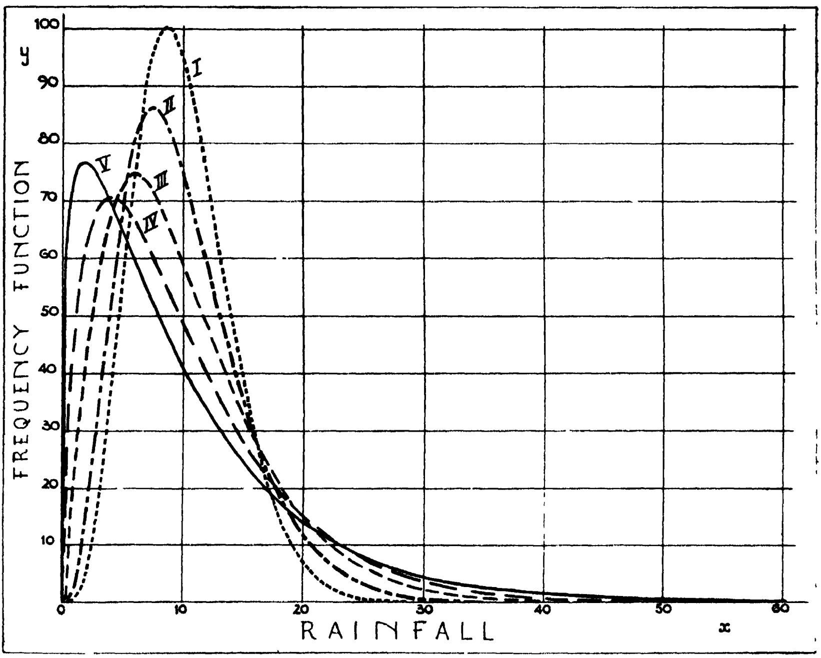

FIG 2 —Frequency distribution of rainfall for one thousand months with mean variability, (i) below 35, (ii) 35–45, (iii) 45–55, (iv) 55–65, and (v) over 65 per cent. Rainfalls are expressed as a proportion of the average, which is denoted by 10 units. The frequency of rainfalls within a given range is indicated by the area enclosed between this range marked on the x-axis and the corresponding section of the frequency curve.

TABLE II.—CONSTANTS FOR THE FREQUENCY DISTRIBUTION CURVES

Mean Variability, per Cent.			Total Frequency.	σ	Mode.	Median.	$\log_{10}a$.	b.	m.	n.
Range.	Average from Original Data.	Average from Graduated Data.								
Under 35 ..	31·6	31·1	2,820	4·01	8·7	9·6	$\overline{25}\cdot53633$	44·945	3·6004	15·0916
35–45 ..	40·1	40·2	6,240	5·11	7·4	9·2	$\overline{149}\cdot30887$	195·905	2·5764	65·5663
45–55 ..	49·6	49·7	4,680	6·39	5·9	8·7	$\overline{73}\cdot05852$	164·932	1·2496	33·8502
55–65 ..	59·1	59·0	2,280	7·64	3·9	8·2	$\overline{68}\cdot00748$	207·609	0·5830	30·2533
Over 65 ..	66·6	66·3	540	8·96	1·8	7·4	$\overline{374}\cdot65365$	1034·86	0·2193	124·3833

Of the 552 sets of thirty months considered, 208 had variabilities of approximately 40 per cent. and 156 approximately 50 per cent. These gave sufficient information for the "goodness of fit" by the χ^2 test to be classed as just satisfactory. The other groups, with more limited data, contained a measure of unevenness which, however, disappears in the frequency curves.

In Fig. 2 the graphs are drawn for the five frequency distributions, which have been reduced to correspond to a total frequency of one thousand months for each group. From the figure or the table it will be seen that in the lowest variability group the mode occurs at a percentage rainfall of 87 and the median at one of 96. With increasing variability the mode decreases rapidly, being only 18 per cent. in the final group, for which the median is reduced to 74 per cent. Hence negative departures of rainfall from average always outnumber the positive ones, and very appreciably so when the variability is large.

After some interpolation with the smoothed data upon which the graphs were constructed, frequencies were derived corresponding to exact values of the variability. These are set out in Table III, which gives in compact form the average frequency distribution of monthly rainfall in New Zealand. Although the average rainfall and the mean variability alone do not uniquely determine a skew frequency distribution, a knowledge of the two quantities (from maps or otherwise) and an acceptance of the results of this table will give a reasonable indication of the probable distribution of the rainfall total for a particular month under New Zealand conditions.

TABLE III.—FREQUENCY DISTRIBUTION OF ONE THOUSAND MONTHS OF GIVEN MEAN VARIABILITY WITH RAINFALL WITHIN SPECIFIED RANGES

Mean Variability, per Cent.	Monthly Rainfall (100 = Average)									
	Below Average.				Above Average.					
	0–25.	25–50.	50–75.	75–100.	100–150.	150–200.	200–300.	300–400	400–500.	Over 500.
20 ..	2	36	158	316	424	60	4	..	..	..
25 ..	4	52	182	286	385	82	9	..	..	..
30 ..	7	75	197	253	357	98	13	..	..	..
35 ..	12	105	206	229	316	107	24	1	..	..
40 ..	23	130	205	206	279	112	43	2	..	..
45 ..	41	150	197	183	250	114	60	5	..	..
50 ..	70	165	184	161	227	113	70	9	1	..
55 ..	98	172	171	147	207	111	77	14	3	..
60 ..	131	176	160	134	187	106	82	19	4	1
65 ..	170	177	150	120	167	95	87	24	7	3
70 ..	208	175	142	103	150	79	94	31	12	6
75 ..	247	169	131	84	135	68	102	37	18	9

As a demonstration, the March rainfalls for Tutira and the February rainfalls for Whanawhana (both in Hawke's Bay) have an unusually high variability of 75 per cent. According to Table III, a locality which has a rainfall variability of 75 per cent. would in thirty years experience rainfalls during the given month scattered as shown in the first line of Table IV. The values there are obtained from Table III by reducing them in the ratio 30 : 1,000/*e.g.*, $\frac{30}{1000}$ of 247 = 7, &c. It may be noted that in

nineteen years the rainfall is likely to be less than average, and above in the remaining eleven years. The following lines of the table give the actual recorded rainfalls for the period 1911–40.

TABLE IV.—NUMBER OF MONTHS WITH SPECIFIED RAINFALL

	Rainfall (100 = Average)								
—	0–25.	25–50.	50–75	75–100	100–150.	150–200	200–300.	300–400	Over 400.
Expected ..	7	5	4	3	4	2	3	1	1
Tutira : March	6	7	3	4	3	3	3	0	1
Whanawhana : February	5	9	4	1	4	2	4	1	0

The observed values depart from the expected ones by an insignificant amount. (In testing this, the χ^2 values are found to be 3·28 and 6·44 respectively, and these correspond to P = 0·8 and 0·4, there being 6 degrees of freedom, 3 less than the total number of classes, as the total frequency, mean, and mean variability are fixed.)

On account of its rather large variability, rainfall averages will depend appreciably on the length of records used. From the standard deviations mentioned in Table II it is found that the probable error in the mean rainfall as determined from thirty years of observations is 5 per cent. for a month in the lowest variability group and 11 per cent. in the highest. Records would need to be extended to a period of 116 years before these probable errors were halved.

III. PERSISTENCE OF MONTHS WITH DEFICIENT OR EXCESS RAINFALL

This section is based on considerations upon "runs" of months all having rainfall departures from average of like signs. The same forty-six stations as were used in the preceding section were examined over the period 1911–40. The results are set out in Table V, showing the total number of runs for the twenty-three stations in the North and South Islands separately, and also combined, as well as the average per station.

TABLE V.—NUMBER OF RUNS OF n MONTHS EACH WITH NEGATIVE OR POSITIVE DEPARTURES RESPECTIVELY DURING 1911–40

—	n.	1	2	3.	4.	5	6.	7.	8	9	10	11.	12	13–16
Negative runs	Total for—													
	23 N.I. stations ..	830	418	260	145	68	61	44	27	15	16	7	3	5
	23 S.I. stations ..	832	476	276	148	86	59	41	12	15	8	5	3	4
	46 N.Z. stations..	1662	894	536	293	154	120	85	39	30	24	12	6	9
	*Total computed ..	1577	934	553	327	194	115	68	40	24	14	8	5	7
	Average per station	36	19	12	6	3	3	2	0·8	0·7	0·5	0·3	0·1	0·2
Positive runs	Total for—													
	23 N.I. stations ..	995	447	247	112	44	22	6	2	2	0	0	1	2
	23 S.I. stations ..	1059	509	217	90	32	25	6	4	6	2	0	0	0
	46 N.Z. stations..	2054	956	464	202	76	47	12	6	8	2	0	1	2
	*Total computed ..	2068	951	438	201	92	43	20	9	4	2	0·9	0·4	0·3
	Average per station	45	21	10	4	2	1	0·3	0·1	0·2	0·04	0·00	0·02	0·04

* See below.

Between the figures for the two Islands there is little significant difference. A sequence of negative departures beyond six months has occurred for the average locality only about four times in the thirty years and a sequence of positive departures less than once. Some details of the longest sequence in the above table are shown in Table VI.

TABLE VI.—LONG SEQUENCES OF MONTHS WITH NEGATIVE OR POSITIVE DEPARTURES

Place.	Dates.	Number of Months.	Rainfall Departure from Average.	
			Inches.	Percentage.
Auckland ..	December, 1913, to February, 1915	15	−25·66	−42
Pakihiroa ..	February, 1930, to March, 1931 ..	14	−41·09	−36
Turua ..	January, 1919, to January, 1921 ..	13	−17·98	40
Portland Island..	April, 1932, to April, 1933 ..	13	−13·67	−41
,, ..	March, 1934, to March, 1935 ..	13	−17·93	54
Oamaru ..	June, 1923, to September, 1924 ..	16	−14·12	49
Nelson ..	November, 1918, to December, 1919	14	−20·02	−45
Tapanui ..	December, 1915, to January, 1917	14	16·99	−34
Timaru .	March, 1915, to March, 1916 .	13	−12·89	52
Whangarei ..	July, 1916, to September, 1917 ..	15	+38·21	+47
Cuvier Island ..	March, 1916, to May, 1917 ..	15	+28·88	+61
Wekaweka ..	October, 1916, to September, 1917	12	+56·30	+53
Peel Forest ..	February to November, 1916 ..	10	+14·17	+44
Invercargill ..	January to October, 1916 ..	10	+14·43	+38

The notable dry years, 1914, 1915, 1919, and 1930, have been discussed by Kidson(4), as also has the drought of the summer of 1934–35(5). After the long dry spell from 1912 to 1915, a wet period followed, and the years 1916 and 1917 have given the longest runs of months with excess rainfall.

It is of interest to examine the frequencies of the runs as given in Table V to see whether there is independence—*e.g.*, whether the occurrence of a run of dry months alters the likelihood that the next should be a dry one also. Of the 16,560 months used, 9,466 had negative and 7,094 positive departures. Hence, on the assumption of complete independence, the average probability of occurrence of a month with a negative departure is $p = \frac{9466}{16560} = 0{\cdot}572$, and of a month with positive departure, $q = 0{\cdot}428$. For the present purpose, only the average value of p is being considered. The number of isolated months with negative and positive departures would then be 16,560 pq^2 and 16,560 p^2q, or 1,735 and 2,319 respectively. However, both these are more than the numbers recorded. The frequencies of shorter runs on this supposition are likewise greater than recorded.

However, if it is assumed that after one or more dry months there is a constant probability, N, that the next will have a negative departure, and after a run of wet months that there is a constant probability, P, that the next month will have a positive departure, the expected frequencies of a run of n months ($n = 1, 2, 3 \ldots$) are expressible as A N^{n-1} $(1 - N)$ or B P^{n-1} $(1 - P)$, A or B being the total number of runs of 1, 2, 3 . . . months for negative and positive cases respectively. In this connection reference may be made to Brooks and Carruthers(6). The computed values, after adopting $P = 0{\cdot}460$ and $N = 0{\cdot}592$, appear in Table V. For positive runs the agreement is satisfactory, but it is still rather poor for negative

runs, of which those of six months or longer are more frequent than calculated. However, this suffices to demonstrate the feature of persistence of type: after a dry month the chance is about 0·592 in favour of another dry month and 0·408 in favour of a wet month; but after a wet month the probability of a dry month is 0·540 and of a wet month 0·460. These values, which are general averages based on a combination of all the records under review, give an indication of the size of the effect, which cannot be considered a large one for most practical purposes.

ACKNOWLEDGMENT

I wish to thank Mr. D. A. De Terte for preparing the figures for publication.

REFERENCES

(1) SEELYE, C. J. (1941): Mean Variability of Annual Rainfall in New Zealand. *N.Z. J. Sci. & Tech.*, *22*, 18B–21B.

(2) ——— (1945): "Maps of Average Rainfall in New Zealand." Air Department, Wellington.

(3) ELDERTON, W. P. (1938): "Frequency Curves and Correlation," 3rd Edn. Cambridge.

(4) KIDSON, E. (1931): Dry Years in New Zealand. *N.Z. J. Sci. & Tech.*, *13*, 79–84.

(5) ——— (1935): The Summer of 1934–35 in New Zealand. *N.Z. Meteorological Office Note 16.*

(6) BROOKS, C. E. P., and CARRUTHERS, NELLIE (1944): "Statistical Methods in Climatology." Meteorological Office, London. M.O.M. 467.

NOTES ON THE CANTERBURY FLOODS OF FEBRUARY, 1945

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Summary

Important meteorological factors in the situation leading up to the heavy rain in Westland and Canterbury during February, 1945, were the presence of a stationary frontal system over the South Island, the arrival of a depression from off New South Wales, and the inflow of cold air following the intensification of an anticyclone to the south of New Zealand.

Strathmore, near Hinds, received 4·70 in. and 9·23 in. on the 20th and 21st respectively, and several other places had daily amounts exceeding 6 in. The rain maps show that the heaviest rainfall occurred in a strip of lowland country parallel to the coast. For several weeks before this storm, precipitation had been above normal, thus increasing the extent of the surface flooding experienced. The month had exceptional rainfall totals for many Canterbury stations.

Erosion and its complement deposition were surprisingly slight in spite of the intense rainfall.

Many slips and slumps were observed on the lower slopes of the mountains, mainly on Hurunui soils and on steep facings of the downlands.

Erosion on the downlands consisted mainly of gully and rill erosion, but the soil loss over the whole of the downlands was inconsiderable, due mainly to the rank vegetation and the small area under cultivation. The amount of erosion was related directly to (1) nature of cultivation; (2) angle of slope. The finer the state of cultivation, the less the angle of slope on which appreciable gully erosion took place. Mass movements, such as soil creep (involving topsoil only) and slumping, were also observed. The latter, under forest and tussock, is regarded as natural geological erosion. Earth movements of this kind are not commonly associated with loess landscapes and are relatively rare in South Canterbury.

Erosion of the plains was limited to streambank erosion and did extensive damage to roads and bridges. Although the rivers spilled widely over the plains, very little silt was deposited, but there was some aggradation in the lower reaches.

INTRODUCTION

DURING the 18th and 19th February, 1945, heavy rain fell in South Westland and in the next two days shifted to the east coast with very severe flooding resulting in South Canterbury. Section I describes the meteorological situation leading up to the storm, Section II contains information on the rainfall, including maps which show its distribution, and Section III gives an account of observations on erosion in the Timaru district.

I. METEOROLOGICAL SITUATION

The sequence of events leading up to the period of heavy rains in Westland and later in Canterbury was rather obscure, and although the following interpretations of the meteorological situation appear to be substantially correct it is not claimed that the analysis is final.

During the period 9th to the 13th February, 1945, a series of weak depressions moved south-eastwards over New Zealand, while an anticyclone remained practically stationary to the south of Campbell Island. However, by the 13th a weak anticyclone had built up to the north of New Zealand and the weak trough of low pressure along which the depressions had been travelling had passed to the east of the South Island. The anticyclonic cell gradually extended its influence over the whole New Zealand

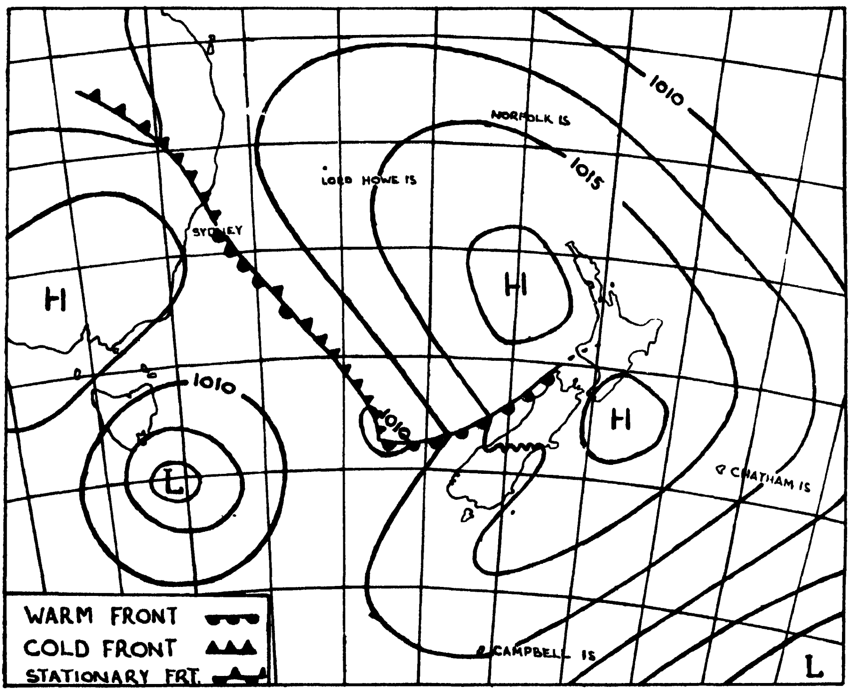

FIG. 1.—Noon, Friday, 16th February, 1945 (N.Z.C.T.).

area, and by noon on the 16th the weather chart (Fig. 1) showed two centres of moderately high pressure (1018 mb.), one located west of the North Island in the Tasman Sea the other between Cook Strait and Chatham Island. A weak front between these two anticyclonic cells gradually appeared as the warm front of a small wave disturbance on a quasi-stationary frontal system extending across the Tasman Sea and reaching the Australian coast near Newcastle. Another depression south of Tasmania was moving slowly eastwards. During the next twelve to eighteen hours the wave disturbance was crossing western Southland, being responsible for thunderstorm activity in the Puysegur Point - Milford Sound area during the early morning of the 17th. The depression had moved eastward off the Otago Peninsula by

evening. As this depression moved farther away, the associated cold front advanced slowly northward across Otago and South Canterbury, reaching as far north as Hokitika, where heavy rain fell just after midday on the 18th. Figures 2 and 3 show the weather situations at noon on the 17th and 18th respectively. The cold front mentioned above did not advance beyond Christchurch or Hokitika, and by the morning of the 19th it began to retreat slowly southwards as a warm front, giving extensive rains in South Westland and with scattered falls in Otago and Southland. Apparently the return of this front was due to the steady approach of the depression which had moved eastwards from Tasmania. The depression was considerably reduced in intensity, however, and lost identity in the Southern Lakes district. Meanwhile a new centre of low pressure was developing just east of Sydney. The front over South Westland and Central Canterbury was

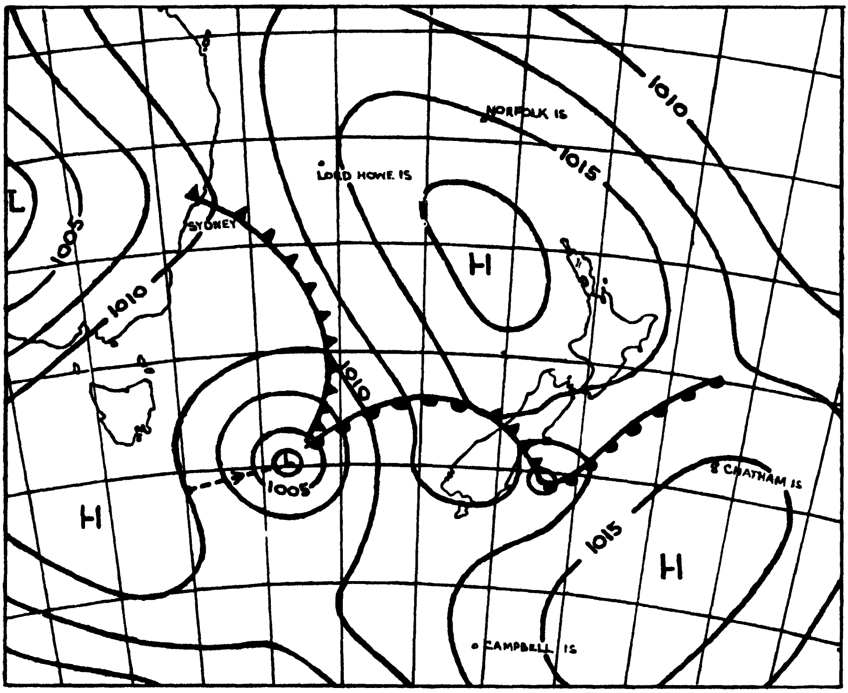

FIG. 2.—Noon, Saturday, 17th February, 1945 (N.Z.C.T.).

thus given no further impetus either north or south and remained almost stationary in that region. It appears, therefore, that the rainfall experienced in Otago, Southland, and South Westland during the afternoon and night of the 19th can be attributed to the combination of this depression and the quasi-stationary front.

From the morning of the 19th, pressures at Campbell and Auckland Islands began to rise steadily as cool southerly air spread towards the South Island behind a secondary cold front. At the same time an anticyclone in the south Tasman Sea began to move eastwards and northwards behind the new depression travelling south-eastwards from the coast of New South Wales. The weather chart for noon on the 19th is given in Fig. 4. The cold front moved on to eastern Southland and Otago about 6 a.m. on the

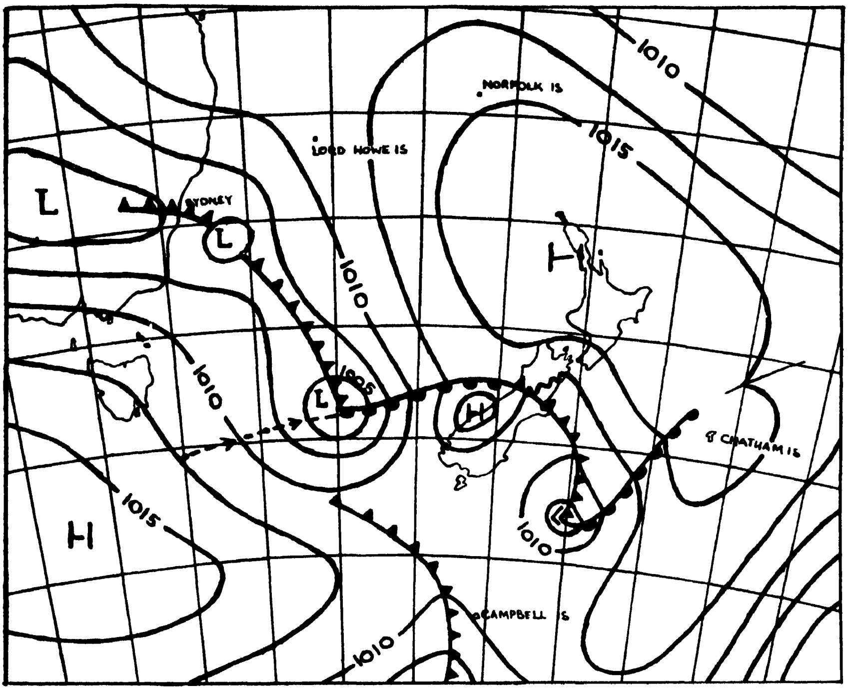

FIG. 3.—Noon, Sunday, 18th February, 1945 (N.Z.C.T.).

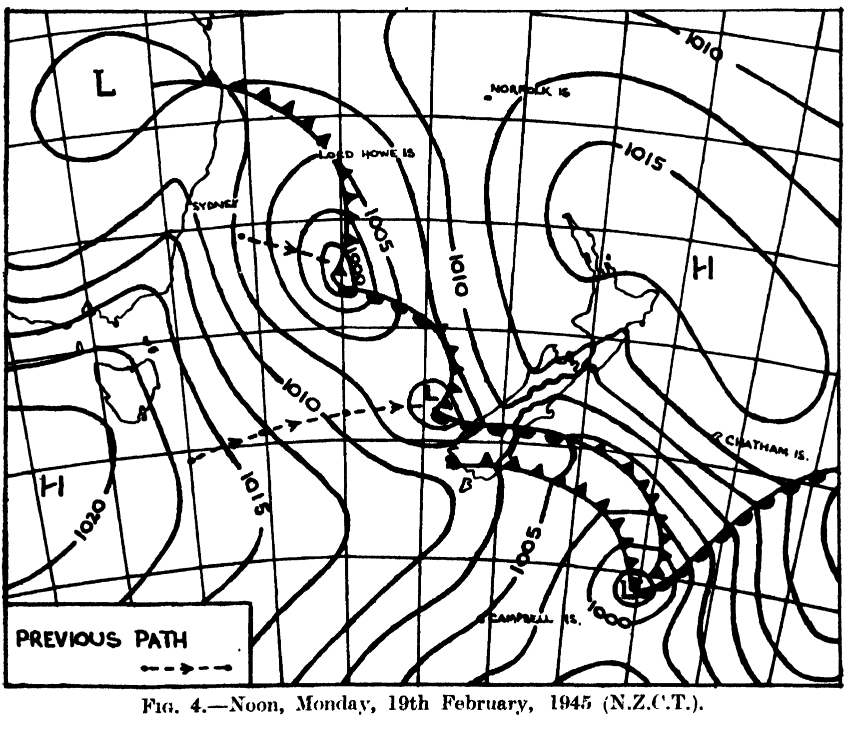

FIG. 4.—Noon, Monday, 19th February, 1945 (N.Z.C.T.).

19th and quickly proceeded northwards to amalgamate with the stationary front still lying across the South Island from Timaru to Jackson's Bay. This strong influx of cold air greatly increased the temperature contrast across the stationary front and led to increased frontal activity. Meanwhile, from the central Tasman Sea the new depression had moved steadily south-eastwards, and the main centre (with a pressure just under 1000 mb.) crossed the west coast between Jackson's Bay and Hokitika at about 3.30 p.m. on the 20th. Consequently, a strong easterly flow of cold air, undercutting the warmer and moister northerly air mass to the north of the front, was forced on to the Canterbury Plains. Figure 5 shows the situation at noon on the 20th. Heavy rainfalls were experienced in the centre of the South Island during the night of the 20th as the depression moved across the Alps, reaching the Pegasus Bay area by the next morning. The rains

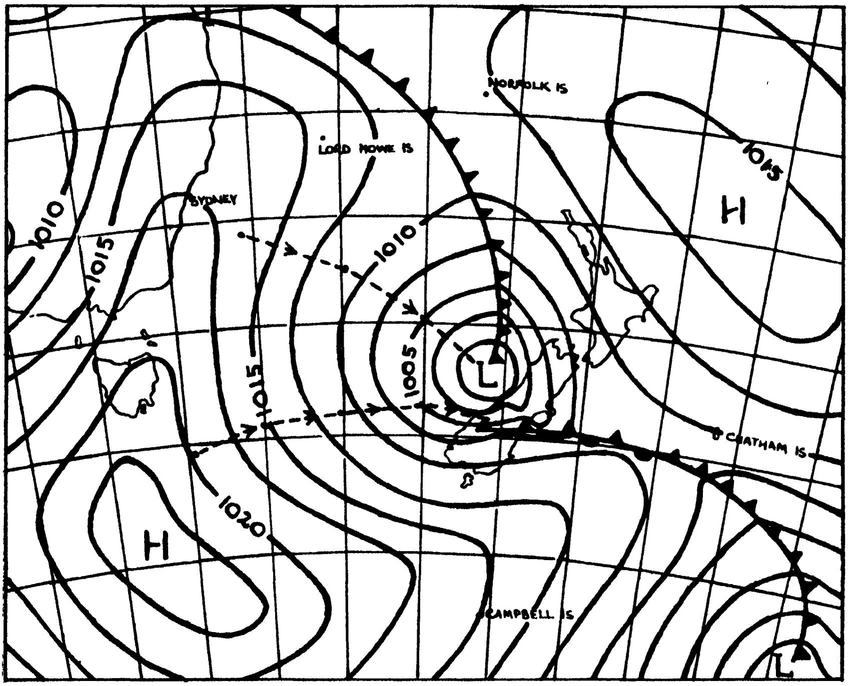

FIG. 5.—Noon, Tuesday, 20th February, 1945 (N.Z.C.T.).

continued, and the winds veered to strong southerlies during the afternoon of the 21st as the low pressure centre (now only 1003 mb.) recurved east-north-eastwards out of Pegasus Bay. Figure 6 gives the situation at noon on the 21st. By morning on the 22nd the pressure gradient having eased considerably, the winds had decreased, and occasional showers with rapidly increasing fair periods replaced the continuous heavy rain of the previous day.

In conclusion, three important features of the week's weather situation are worthy of note. First, the development of the quasi-stationary front across the South Island; second, the development of a depression east of Sydney and its advance south-eastwards to Westland; third, the simultaneous intensification of an anticyclone to the south of New Zealand which subsequently redirected the depression east-north-eastwards, the turning point in mid-Canterbury being the region of maximum rainfall.

Grateful acknowledgment is made to Mr. J. W. Hutchings for helpful suggestions concerning the analysis of this series of weather maps, and to Mr. D. A. De Terte for drawing the diagrams for reproduction.

II. RAINFALL

The accompanying isohyetal maps (Figs. 7 11) show the distribution of the rainfall for each of the four days from the 18th to 21st February, 1945, and for the whole period. Figure 12 gives the total amount for the two wettest days in Canterbury-- namely, the 20th and 21st, most of the rain having occurred within about thirty-six hours. East of the Southern Alps the zone of maximum precipitation extended from Glentunnel to Waimate, with the axis roughly parallel to the coast. Rainfall attained its greatest

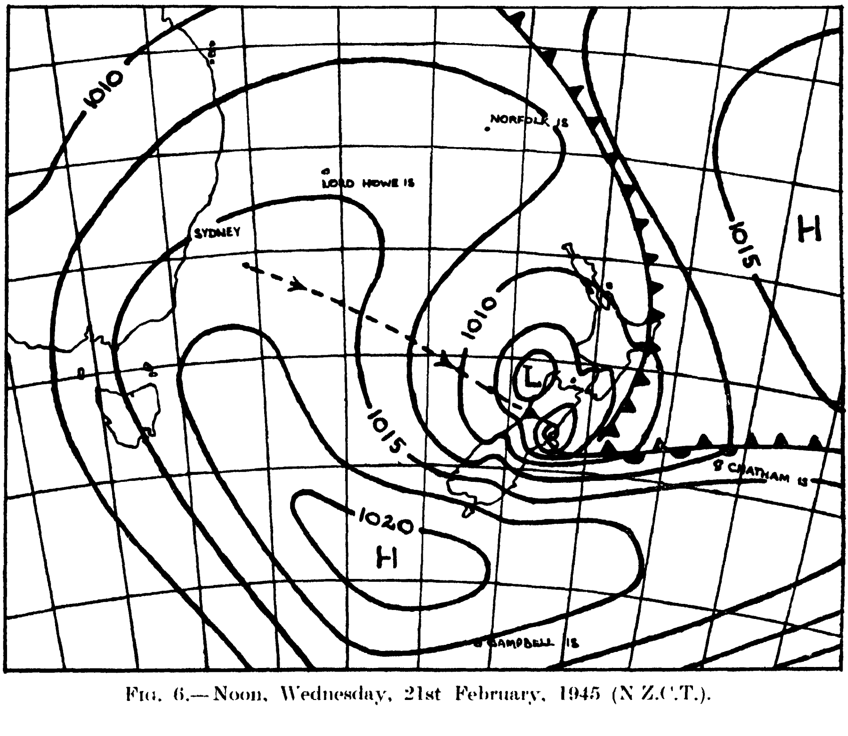

FIG. 6.—Noon, Wednesday, 21st February, 1945 (N.Z.C.T.).

intensity between Hackthorne and Pleasant Point and in a narrow belt farther south to Hunter. The most outstanding fall was 13·93 in. recorded at Strathmore within forty-eight hours. The maps show how the Southern Alps and their foothills experienced lesser falls than a large extent of low country. As in many other exceptional rainstorms, the influence of orography is not conspicuous and the rain pattern bears no resemblance to the average distribution of precipitation

Some details of the heaviest falls in the South Island between the 16th and 21st are given for official rainfall stations in Table I, which includes all cases of daily amounts exceeding 6 in. or of aggregates exceeding 9 in. Except north of Cheviot, any rain recorded for the 22nd was only a few points. All references to daily rainfalls are to the twenty-four hours commencing at the morning observational hour.

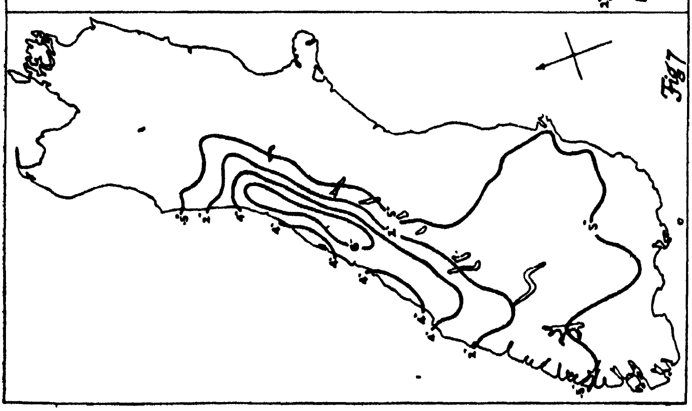

FIG. 7.—Daily rainfall, 18th February, 1945.

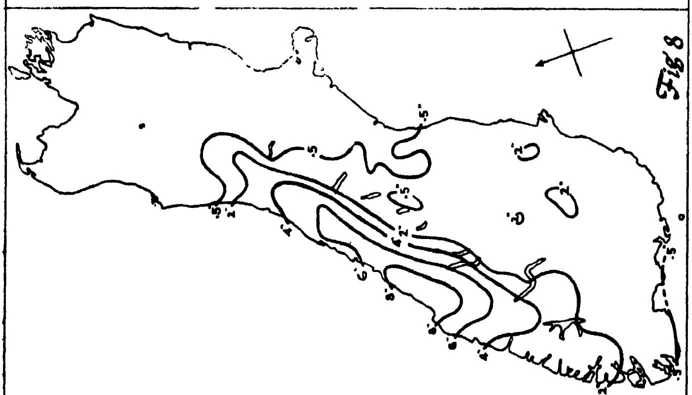

FIG. 8.—Daily rainfall, 19th February, 1945.

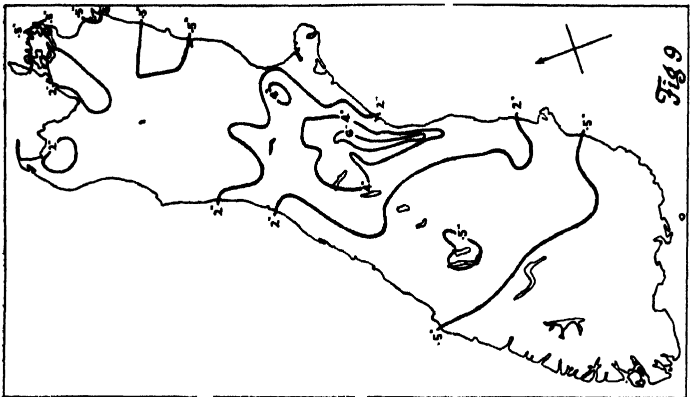

FIG. 9.—Daily rainfall, 20th February, 1945.

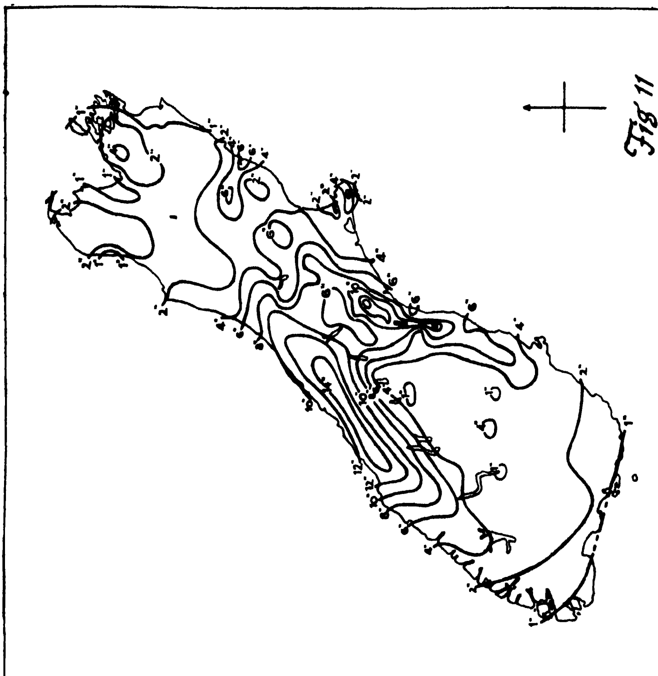

FIG. 11.—Total rainfall, 18th to 21st February, 1945.

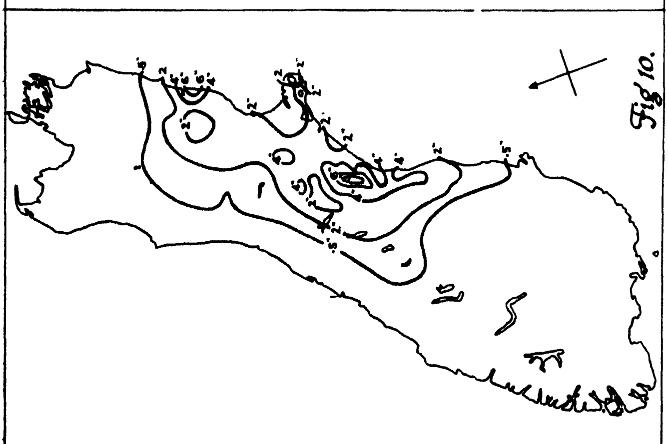

FIG. 10.—Daily rainfall, 21st February, 1945.

TABLE I.—DAILY RAINFALL IN POINTS (100 POINTS = 1 IN.), FEBRUARY, 1945

—	16th.	17th	18th.	19th	20th	21st.
Westland—						
Okarito	75	185	365	588	116	..
Wataroa	70	155	555	586	87	..
Waiho	99	*	582	625	138	..
Weheka	49	121	526	721	79	..
Karangarua	26	124	445	542	136	..
Haast	198	94	300	829	97	..
Jackson's Bay	366	66	410	819	78	2
Mount Cook: The Hermitage	..	60	520	370	259	36
Canterbury—						
Hawkswood	..	.	.	Tr	38	679
Hackthorne	..	..	..	.	500	502
Winchmore	.	..	.	2	415	564
Omagh (near Mayfield)	..	.	..	4	540	496
Strathmore (near Hinds)	.	2	..	10	470	923
Orari Gorge	1	10	3	71	610	497
Geraldine Downs	..	..	7	31	554	577
Orari Estate	.	3	4	16	394	790
Kakahu	..	Tr.	6	5	689	433

* Included in the following day.

Figures received from private recorders are Claremont (P. R. Talbot), whole period, 1,375 points; and Hunter (J. W. Armstrong), the 19th to 21st, 162, 645, and 470 points.

For ten Canterbury stations in the wettest zone, averages have been taken out to indicate the rainfall for some time before the storm.

TABLE II.—RAINFALL SUMMARY FOR TEN STATIONS FROM HACKTHORNE TO PLEASANT POINT

Month	Mean Rainfall, in Points.	
	Previous Years	Summer 1944-45.
December	311	950
January	304	408
February	274	1357

Over these stations the averages for February, 1945, were: 1st to 17th, 269 points; 18th, 3 points; 19th, 28 points; 20th, 525 points; 21st, 532 points.

The exceptionally wet December of 1944 was followed by a January with a slight excess of rainfall, and before the main storm had set in, February had already received a rainfall approaching normal. The land was thus well saturated and surface flooding soon developed. Extensive flooding occurred in every creek and stream, towns were finally isolated with communications disrupted, widespread damage was done to bridges, and farm lands and stock suffered seriously from the inundations.

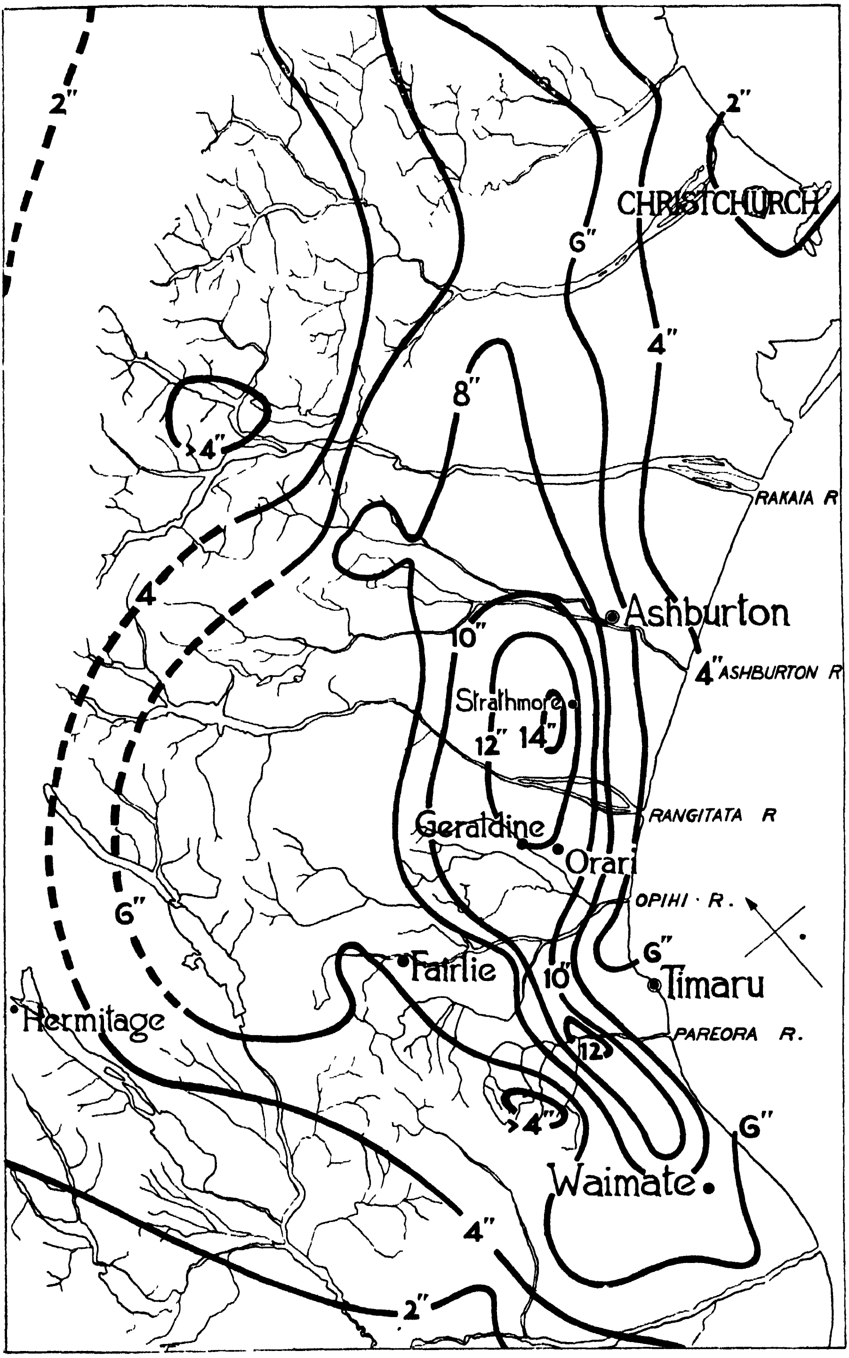

FIG. 12.—Total rainfall, 20th and 21st February, 1945.

Long-standing records for daily rainfalls were surpassed for comparatively few places, but for many it was a record two-day fall. The 20th February, 1936, was, for example, a wetter day for both Ashburton and Timaru. Two other unbeaten amounts for single days are included in the two examples below :—

Springburn, May, 1923—	Points	Orari Gorge, March, 1941—	Points.
3rd	109	15th	9
4th	77	16th	105
5th	175	17th	296
6th	788	18th	638
7th	291	19th	141
8th	88		
9th	5		

The following localities, for which available records go back thirty years or more, experienced in February, 1945, the heaviest total rainfall for any calendar month previously. After the station names are noted the amount for February, 1945, and also the year of the first rainfall records: Hackthorne, 12·75 in. (1906) ; Hororata, 11·28 in. (1891) ; Evandale, 10·58 in. (1912), with December, 1944 (10·43 in.), its second wettest month ; Winchmore, 12·65 in. (1890), with the one exception that December, 1944, 13·31 in. takes first place ; Orari Gorge, 15·61 in. (1899) ; Orari Estate, 14·97 in. (1898) ; Kakahu, 14·13 in. (1910) ; Pleasant Point, 10·68 in. (1903) ; Seadown, 8·44 in. (1914) ; and Waimate, 11·70 in. (1897).

Although February, 1944, was also wet for South Canterbury, February, 1936, was hitherto the wettest February since the 1890's or earlier. May, 1923, remains the record of all months in many parts of North Canterbury, and March, 1902, narrowly retains its record in the Timaru region. Few meteorological records are available for February, 1868, when outstanding floods occurred in South Canterbury. On that occasion an extensive depression passed over New Zealand, and rain, brought by winds from an easterly quarter, amounted to 8·08 in. at Mount Peel on the 3rd.

III. EROSION

The soil erosion which took place during the flood of 21st February, 1945, may be regarded for convenience as affecting three groups of soils :—

(1) The mountain soils.
(2) The soils of the downlands.
(3) The soils of the plains.

(1) *The Mountain Soils*

The mountain soils, excepting those covering the lower eastern flanks of the ranges, are variously eroded from moderate to severe. Run-off is high, and sheet erosion takes place readily. Erosion is most active on the upper slopes, covered by soils of the Kaikoura series. The lower slopes (mainly soils of the Hurunui series) have a good cover of vegetation and erosion is much less active.

Only the lower slopes of the mountains have been examined since the flood, which was much less intense on the mountains than on the plains and downlands. On the mountain slopes many slips and slumps were observed under tussock, scrub, and gorse. The number, size, and distribution of these mass movements have not yet been assessed, but their economic importance is relatively small when compared with the erosion of the downlands.

(2) *The Soils of the Downlands*

The soils of the downlands are derived almost exclusively from loess. In the west there are some small areas where the soils are formed on sandstone of Tertiary origin. The texture of the downlands soils is uniformly a silt loam, which is very susceptible to sheet erosion. Slips and slumps, however, are rare, except on the steeper sandstone slopes near the ranges.

The principal consequences of prolonged and heavy rain on the rolling slopes of the downlands are gouging of gullies and the removal of topsoil by sheet erosion. The total sum of erosion during the February flood was relatively slight, though a few isolated fields showed more intensive erosion. During the summer months preceding the flood, rainfall had been plentiful and well distributed. Pastures were therefore rank. At the same time, there had been little cultivation, and a bare soil surface was exposed on only a small part of the downlands. Consequently, although it was already saturated and rainfall was intense, the soil was protected from the erosion which might have been expected by the dense vegetative cover.

Sheet and Gully Erosion.—No sheet erosion, in the sense of the removal of topsoil as a sheet, was observed during the flood. At the height of the flood the water did not flow uniformly over the surface of the soil, no matter what the nature of the cultivation, but rather as a multitude of small streamlets and rills. The more regular the surface contours, the more the small rills tended to coalesce into larger streamlets. Thus, a coarsely cultivated field broke up the run-off waters into many small rills, but a finely cultivated one encouraged them to unite.

After the flood, all cultivated fields (excepting those still in furrow, which were not eroded) presented a pattern of innumerable small rills from 1 in. to 6 in. deep and from 1 in. to 36 in. wide. Rills less than 4 in. deep soon lost their sharp contours and after a few months were almost imperceptible. Where the field was subsequently cultivated the rills were, of course, obliterated, and only those more than 6 in. deep remained. After a few months there were no traces of any but the deepest gullies.

On the Claremont and Gleniti silt loams, the two soil types characteristic of the downlands of Levels County and Geraldine County to which this brief survey of the immediate effects of the flood is confined, it was observed that the amount and degree of erosion were related directly to nature of cultivation and angle of slope. Most uncultivated fields were not eroded. Only one gully on an uncultivated slope steeper than 18° was observed. This was on a slope of 25° near the foot of a 200 ft. hillside. Under grassland, where undulations had concentrated the run-off waters into streams, and where roadsides, sheep-tracks, and implement-tracks formed natural channels, there were moderately deep gullies up to 2 ft. in depth. Gullies formed at the bottom of gentle undulations should probably be regarded as temporary rejuvenations of the drainage channels brought about by the sudden increase in the volume of water and therefore classed as natural erosion.

Cultivated fields varied a good deal in degree of erosion. Recently ploughed fields, if not broken down further, did not erode. As far as could be observed, this was entirely independent of the direction of ploughing, whether along the contour or along the direction of maximum slope. A field still in furrow so broke the force of the rivulets that they could achieve little in the way of erosion. Even when the furrows were directed down the slope, the cohesion of the overturned furrow and the irregular nature of the channel in between seemed to prevent any substantial erosion. Perhaps

a good deal of water soaked through into the cavities under the furrow, where movement was slow and water was flowing on compact and undisturbed soil. A field even in coarse clods such as might be obtained by disking after ploughing did not gully, but where a fine tilth had been obtained by harrowing or other fine cultivation, moderate gullying took place on slopes as gentle as 7°. Although the direction of ploughing appeared to have little effect on the degree of erosion, the direction of sowing was significant. In one field of mangels planted up and down the slope a gully had developed between each row. In this field, at the foot of a 9° slope 80 yards in length, silt had collected to a depth of 18 in. in a depression 8 yards wide. From a similar slope 100 yards long planted along the contour a deposit of silt only 2 yards wide by 2 in. deep had accumulated. Wheat paddocks in which the wheat was still standing showed no gullying, but where the crop had been reaped, gullies developed on slopes of about 14°.

The general effect of angle of slope on gullying may be summarized as follows :—

State of Cultivation.	Minimum Slope at which Gullying began.
(1) Finely harrowed, unplanted	5–7°.
(2) Finely harrowed, root crops up and down the slope ..	5°.
(3) Finely harrowed, wheat stubble	12°.
(4) Finely harrowed, wheat standing	14°.
(5) Ploughed or large clods	16°.
(6) Undisturbed pasture	25° (one only).

No correlation between length of slope and degree of erosion was observed.

Soil Creep.—Soil creep (Sharpe, 1938) was limited to the topsoil and was observed only where this had previously been finely cultivated. Such topsoil when saturated moved downslope readily. One field of mangels on a slope of 9° showed signs of soil creep involving the topsoil to a depth of 5 in. The mangels were moving with the topsoil and were being gradually turned over by the movement.

Slipping and Slumping.—Slipping and slumping are not commonly associated with loess landscapes and are unusual in South Canterbury. They involved only slopes greater than 20° and were not observed on cultivated soils. Slips occurred under both forest and grassland and seemed to have no relation to vegetation. Most of the slipping and other mass movements took place in the narrow belt of foothills at the base of the ranges where slopes were steeper and where sandstone soils are common. These slips do not appear to be related to human interference with the vegetation, but occurred under natural tussock cover, forest, and introduced grassland, and must be regarded, pending further proof, as natural geological erosion—that is, soil movement which would have taken place under the primitive cover.

The significance of these movements to the soil conservationist lies in the future treatment of their products on farm lands. Both the scar and the slip debris should be protected at least as well as it would have been under primitive conditions.

(3) THE SOILS OF THE PLAINS

The soils of the plains are alluvial in origin and range from stony and bouldery loams to fine silt loams. Stream-bank erosion (lateral corrasion) is common and takes a heavy toll of bridge approaches, bridges, and roads during times of heavy flood. Although the total area of soil destroyed by erosion of this kind is small, most of the topsoil lost to agriculture in this way is from the recent alluvial soils which flank the stream-beds and which are the most fertile soils of the plains.

Erosion.—During the flood, erosion was confined to stream-bank erosion, and was widespread throughout the whole district. The area of topsoil lost was small, and most of the disorganization which followed the flood was caused by the destruction of bridges and roads.

Deposition and Aggradation. Where streams bearing loads of waste spread over gently sloping plains, the phenomena of deposition have an important bearing upon agriculture. In previous South Canterbury floods extensive deposits of sands and gravels have been laid by heavily wash-burdened flood-waters over adjacent river-flats, and much fertile land has been buried under unproductive sediments.

The material transported by streams may be regarded broadly as being of two kinds: (*a*) *bed load*, coarse material which serves to aggrade the stream bed itself; (*b*) *wash load*, the fine material which is spread over fields by unconfined flood-water or is deposited on the floors of ponding areas, such as dams, lakes, or lagoons near river mouths. These two groups of sediments differ in both origin and method of transportation.

(*a*) *Bed load* is that part of the load which moves at a rate directly related to the discharge of the stream, and is made up of coarse material (coarse sand, gravels, stones, and boulders) which moves by rolling or sliding along the stream-bottom or by long jumps while in temporary suspension between points of contact with the bed.

Bed load in flood times is derived from material already present in the stream-bed before the flood urged it downstream, and, moving slowly, it advances only a short distance. Very little is added to the stream-bed by each flood, and this exclusively in the upper reaches.

Aggradation in the lower reaches of the stream takes place mainly through accumulating bed load in that part of the course where gradients flatten out. However, aggradation during a flood is not related directly to the erosion taking place over the whole catchment. Most of the material aggrading the lower reaches of a river was already in the bed before the flood and had been derived from erosion in the ranges long before. The only material added during the flood (with the exception of a small amount produced by lateral corrasion of river-banks) consists of rocky debris fed into the upper reaches, and this might need many floods to transport it to the part of the river course where maximum aggradation takes place (in the lower reaches).

Although no surveys are available to fix the exact degree of aggradation in the lower reaches of the Pareora, Opihi, Hae Hae Te Moana, Waihi, and Orari rivers, a rough inspection suggests that this has been considerable, especially within a distance of three to six miles from their mouths.

(b) *Wash load* is that part of the waste load which moves in true suspension at a rate not directly related to the discharge of the stream, and is composed of fine material (fine sand, silt, and clay) (Johnson, 1941). Wash load is directly related to the vegetative state of the catchment at the time of the flood, since most of it is carried into the stream by the run-off waters during the flood.

The wash load borne by the principal South Canterbury streams during the flood was very small. The vegetation was so rank and there was so little land under cultivation that erosion on the downs was reduced to a minimum. On the ranges, rainfall during the flood period was lighter than on the downlands and erosion was therefore relatively slight. After the flood-waters had subsided it was found that the streams had deposited very little sand and silt where they had spread beyond their normal confines, except in the immediate neighbourhood of their beds. Estimates of the sand and silt loads were limited to observations of the amounts deposited by the flood-waters, for it was impossible to reach any of the flooded rivers to collect water samples. The only appreciable deposit of sand was at the mouth of the Opihi River, but this was relatively insignificant considering the extent of the flood.

Along the roadsides and fields, where they had been swept by flood-waters, there were many ridges and piles of gravel, but these had been carried only a short distance as bed load.

APPENDIX

The damage sustained in the Geraldine County, which received the brunt of the storm, is summarized from information kindly supplied by Mr. J. R. Hawkridge, Engineer to the County Council. The number of bridges completely destroyed numbered twelve, eleven were badly damaged and impassable, while the approaches to another twenty-five suffered washouts. Stretches of road up to two miles in length were bared of metal, and numerous small washouts made roads temporarily impassable. Slips completely blocked roads in relatively few places.

REFERENCES

JOHNSON, J. W. (1941): *Soil Conservation* 6, 290.
SHARPE, C. F. S. (1938): "Landslides and Related Phenomena." Columbia University Press, New York.

NOTES ON THE SUSPENDED LOAD OF THE WAIMAKARIRI RIVER

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THE incentive for the compilation of this note was the courtesy of Mr. John Woods, C.M.G., formerly Chief Engineer of Public Works, in supplying the writer with some figures derived from a study of the suspended load and water-discharge of the Waimakariri River which had been carried out under his direction during the period October, 1927, to April, 1932. The figures

* Read before the Otago Branch of the Royal Society of New Zealand, 13th November, 1945.

as first received gave the monthly averages for the suspended load and water-discharge during that period. Grouping the fifty-four pairs of figures into several ranges, taking the average of the quantities within each range, and plotting the one series of averages against the other made it clear that the average suspended load varied in rough proportion with the cube of the corresponding average water-discharge. The recognition of this relationship is the sole original contribution made by the writer of this note. It was suggested, however, that it would be of interest to investigate the relationship further by a more detailed analysis of the figures recorded. This was done under Mr. Woods' direction, and the writer was given the original of the curve (Fig. 1) based on the average values of fourteen pairs of figures within as many ranges of quantities for suspended load and water-discharge. The cube relationship is still more closely illustrated by this curve (hereinafter termed the $S = kQ^3$ curve), and as the matter seemed likely to be of interest to geologists, Mr. Woods very kindly made the writer free to set out the results in this paper. Search was therefore made for record of comparable investigations, and the following notes were compiled.

Professor Straub (1942) states that there is, at least for many rivers, a well-defined relation between water-discharge and the amount of sediment transported in suspension. "Of course, the amount of material found in suspension on any day may deviate greatly from the average for the existing stage, depending on the conditions of the surface of the drainage area, the location of the concentrated precipitation in the area, and other factors." As an instance of this he gives the average curve with plotted daily departures based on daily observations of the Missouri River at Kansas City over a period of two years. The $S = kQ^x$ equation for this curve is of the form $S = 30{\cdot}4 \times 10^{-11}\ Q^{2{\cdot}16}$ where S is the suspended load and Q the water-discharge in tons and cubic feet per second respectively. It is shown that, though the daily deviations of the computed and measured values are considerable, the tabulated monthly averages are in close agreement with the above equation. It was further remarked that for other rivers, and even for different localities on the same river, the coefficient and the exponent in the equation might both be different from those given above. Thus for the Red River, in south-eastern United States of America, the equation is of the form $S = 95 \times 10^{-10}\ Q^{2{\cdot}036}$ (Campbell and Bauder, 1940), while that for the Po River, in northern Italy (Indri, 1935), is of somewhat similar form. "Usually the suspended load seems to vary approximately as the square of the water-discharge, but the relation is entirely different" (Straub, 1942). The equation for the Waimakariri River, with the same meanings attached to S and Q, would be in the form $S = 2 \times 10^{-11}\ Q^3$, with so great a difference in the value of the exponent from those in Straub's citations that it may be of interest to note in what the difference may lie.

The method adopted for estimating the suspended load in the Waimakariri River was that followed in the older investigations of the Po River – that is to say, the amount of sediment collected in a standard bottle opened at a point 0·6 of the total depth from the surface was ascertained at a number of points at appropriate intervals in the river cross-section. (The destruction by fire of the records of the Waimakariri Trust Board prevented more detailed information being presented as to the placing of the collecting points in the river cross-section.) The writer does not know whether Indri's (1935) measurements on the Po River followed the older methods. The study on the Red River followed slightly different lines (Campbell and Bauder, 1940). Straub's (1942) method was a refinement of the older Italian procedure based "on a mathematical analysis involving systematic integration of the

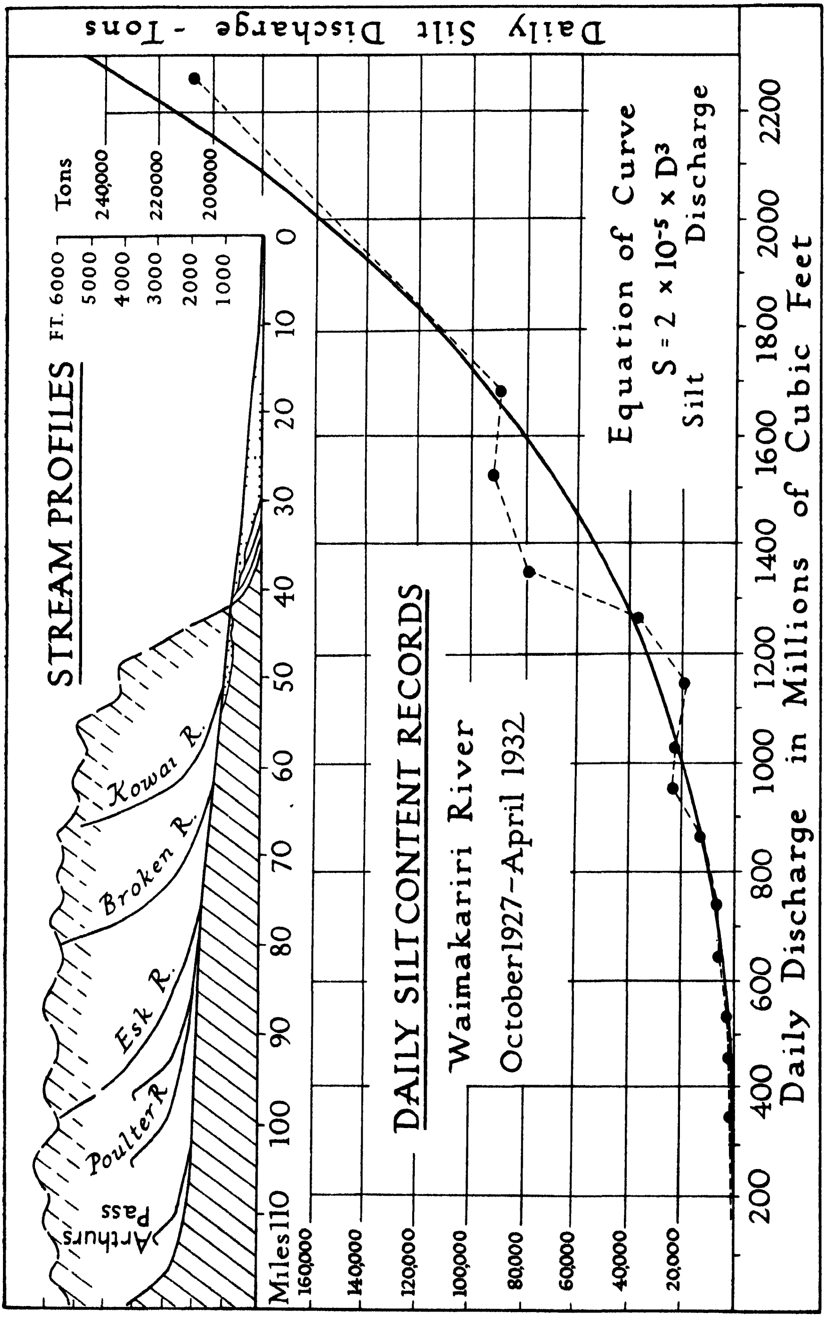

FIG. 1.—$S = kQ^3$ curve showing the relation between the average daily water-discharge and amount of silt transported by the Waimakariri River.

products of suspended load distribution curves and stream velocity distribution curves" developed into the form $S = (\frac{3}{8} S_{0\cdot 8d}$ plus $\frac{5}{8} S_{0\cdot 2d})$, in which S is the sediment-discharge per unit width of stream and $S_{0\cdot 8d}$ and $S_{0\cdot 2d}$ respectively the sediment-concentrations at 0·8 and 0·2 depths from the water surface respectively and the water-discharge of the river per unit width at the point of observation. This is sufficiently close to the method of estimation adopted for the Waimakariri River to leave little ground for the belief that the difference between the two methods of sediment determination is the explanation of the difference between the two derived exponents of the value Q. It may therefore lie chiefly in difference in river-regimen: it is obvious that the regimens of the four rivers mentioned are very different. The characteristics of the Waimakariri River are here briefly summarized, it being then left to those familiar with the characteristics of the other rivers to point out what may be the dominating characteristics which have given them so different a $S = kQ^x$ curve. The details here given are summarized and generalized from those set forth by Speight (1928), Wood (1933), and Cumberland (1945), other authoritative, though scattered, sources of information being utilized in preparing Fig. 2.

The course of the Waimakariri River falls into two distinct portions, an upper portion with its tributaries constituting the water-catchment areas, and the lower portion traversing an alluvial fan, receiving no additional supply but losing water through slight artificial deviations and some lateral percolation. The catchment-area is about 950 square miles, lies almost wholly on highly jointed, steeply dipping argillites and greywackes, and is surrounded and subdivided by ridges rising to heights of 6,000–7,500 ft. above sea-level The head-water valleys fall rapidly to elevations of 2,500–2,000 ft. They were once glaciated, forming a dendritic glacier reaching a maximum length of fifty miles, the main "stem" of which occupied the relatively gently inclined main valley now between elevations of 2,500 and 2,000 ft. with a wide deeply alluviated and braided floor, and containing *in situ* but little of the former glacial deposits, moraines, or varied sediments. Beyond this large eastward-flowing course the river turns southwards and passes through a gorge cut 200–300 ft. into its former bed-level, an antecedent valley through the recently relatively elevated eastern margin of the mountainous tract. It leaves this still in a gorge about 200 ft. deep cut below the westward limits of the former alluvial fan of the river, its course across which forms the second portion of the river.

The very jointed nature of the rocks within the catchment area makes them yield readily to frost action, so that many of the higher ridges are covered by downward-creeping screes, the descent of which has been hastened by the weakening of the scanty cover of tussock grasses through over-grazing and over-burning. Below the 5,000 ft. contour line a sparse sub-alpine scrub exists which in turn gives place at about 4,000 ft. elevation to birch ("beech") forest, of which nearly 180 square miles remains within this water catchment. Much of this has been cleared, however, below the 3,000 ft. contour lines, and here soil erosion has been accelerated by the processes noted above (Cumberland, 1945). Much of the higher land is snow-covered during the winter months, but neither snow-melting nor the melting of the few remaining valley head glacierets contribute essentially to the flood waters of the river. These result from the dominant moisture-bearing north-westerly winds, which give a very variable but very high rainfall on the Southern Alps, averaging nearly 200 in. per year, but

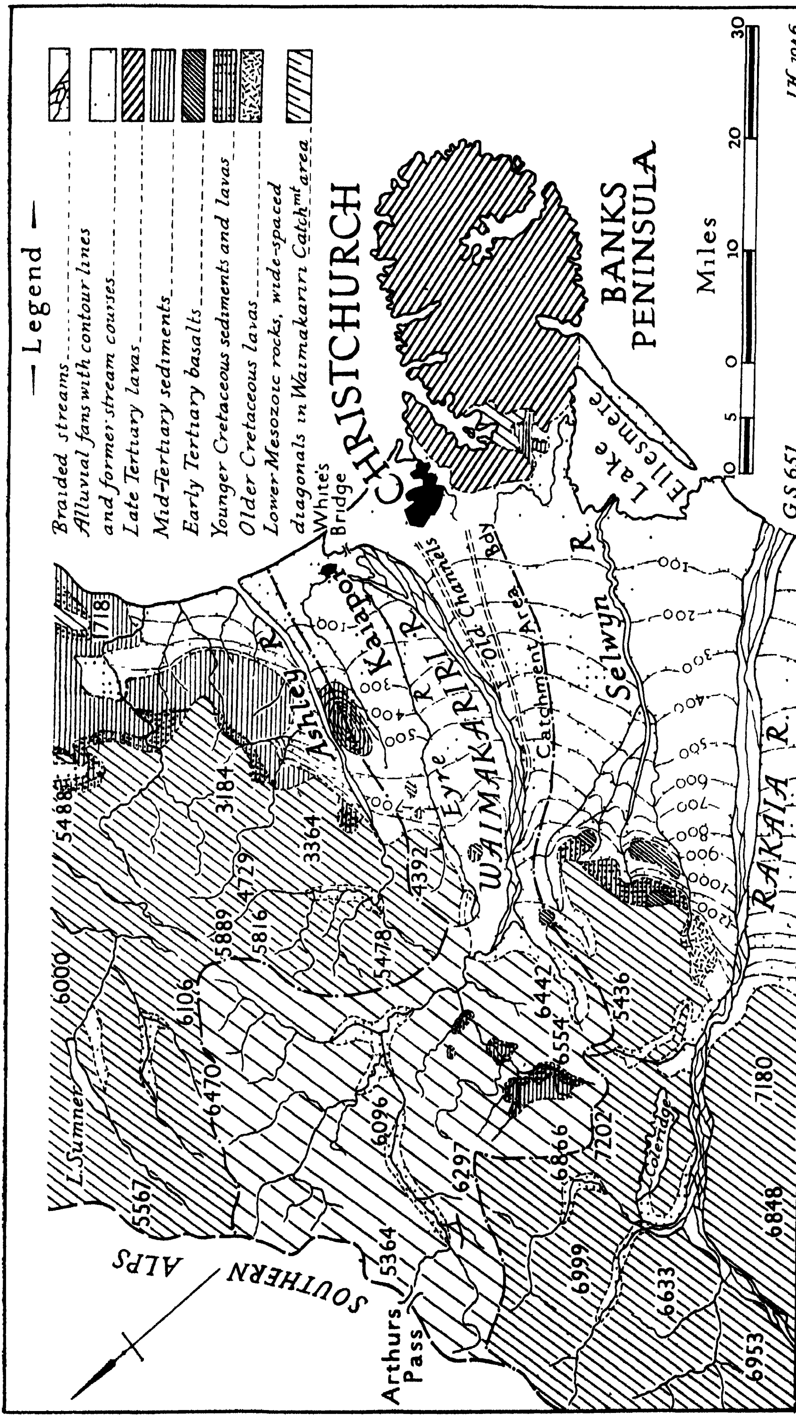

FIG. 2.—Geological map of the Waimakariri River basin. (After Speight and others.)

diminishing rapidly eastwards, and averaging only about 35 in. per year on the eastern margin of the Waimakariri catchment area. The 68·7 in. average rainfall for the catchment area deduced from the records of the six observation stations within it is, however, much less than the true maximum value, for the annual run-off derivable from such an average precipitation throughout the catchment area is notably less than the measured run-off (Furkett, 1933). The largest measured discharge from this catchment near to where the stream enters into the area of the alluvial fan was 135,000 cusecs, but it would seem that a flood of 150,000 cusecs has occurred during the last seventy years (Wood, 1933).

The lower portion of the river begins in a gorge over 200 ft. below the top of the elevated and seaward-tilted alluvial fan, here 1,300 ft. above sea-level and about fifty miles from the coast. The river passes in a narrow gorge through inliers of the Lower Mesozoic and the Cretaceous and Tertiary rocks on to which it was superposed on cutting through the fan-gravels. Eastward of this the river channel becomes several miles wide and much braided, enclosed by gravel banks which rapidly decrease in height downstream until they are only 15–20 ft. high about twenty-five miles from the coast. Six miles from the coast and near the head of tidal influence the channel suddenly constricts to a width of about 1,000 ft. and is here crossed by White's or Empire Bridge, from which were made most of the measurements utilized in constructing the $S = kQ^3$ curve figured. Between the discharge-measuring station near the gorge where the river leaves its catchment area and the lower measuring station on White's Bridge there is no addition to the river flow (other than by rain on the channel floor), and there may be some loss of water-volume by lateral percolation into the gravels of the alluvial fan, which feed the artesian wells of Christchurch (Speight, 1911), a loss which is small according to four pairs of estimates of small and moderate flows given by Speight (1928), but quite considerable according to a pair of observations of discharges of a moderate flood cited by Furkett (1933) made at the upper and lower measuring-stations respectively. Possibly the combined effect of accelerated soil erosion in the catchment area and loss by lateral percolation may have influenced the value of the exponent in the $S = kQ^3$ relation determined beyond the percolation region.

Another apparent anomaly in the amount of the suspended load may be noted. Furkett (1933) called attention to the following table, given by Woods (1933) for measurements at White's Bridge :—

Year.	Water-discharge of River in Cubic Feet per Year	Silt Transported in Suspension per Year.
1928	$148,720 \times 10^6$	878,900 tons
1929	$180,620 \times 10^6$	2,734,000 tons
1930	$161,350 \times 10^6$	1,749,000 tons
1931	$142,800 \times 10^6$	2,206,000 tons

Contrasting the relatively small amount of suspended load transported by the discharge of 1928 with the almost tripled quantity carried per unit of discharged water during 1931, it is held that this difference may result from the fact that the heavy floods of 1926–27 had removed most of the readily transportable silt from the river-bed, and that it was not until two or three years later that there was sufficient fine sediment available on the river-bed to be taken up into turbulent flood waters. Nevertheless, it was during these years that the daily observations were accumulated which,

when analysed, gave the $S = kQ^3$ relation that was unknown to Mr. Furkett at the time his comments were made. Hence another possible factor in producing the relations shown in the above table may be noted—namely, the very great short-time effect of the high value of the exponent in the $S = kQ^3$ relation. It was noted that, though the deviations from the curve are small when averages of daily measurement (*not* individual daily measurements) are considered, they are notably larger when averages of monthly totals are considered, as was shown by the plotting of the monthly average curve which suggested this more detailed study. They would probably be still greater if yearly totals were considered, as a result of differences from year to year in the number, duration, and intensity of the floods. Consider three hypothetical cases in a river like the Waimakariri, with an average daily regimen expressed by $S = kQ^3$. In case I a constant average rate of flow is maintained throughout the year. In case II during six days of the year the river flows with five times its normal discharge. The total water-discharge throughout the year is increased by about 10 per cent. but the total weight of sediment transported during the year rises to about two and a half times its former value. In case III the river is in flood for three days only, but the discharge during those three days is ten times more than the normal daily discharge. The total annual discharge would be the same as in case II but the total amount of sediment transported throughout the year would be four times as great as in case II and ten times as great as in case I, provided that sufficient sediment was available for the stream to transport. It will be noted also that greatly increased amounts of detritus are supplied to streams during flood periods by soil-wash into minor tributaries. These over-simplified cases (which allow a little for the effect of rising and falling flood periods) may, however, serve to indicate the care which must be exercised in arguing from such a table as that given above. "A large proportion of the total load may be carried in a few days" (*cf.* Gilbert, 1884; Andrews, 1911; Howard, 1942)

ACKNOWLEDGMENTS

The writer's thanks are due to Mr. J. Woods, C.M.G., for supplying the monthly average figures for the Waimakariri River and later the original of Fig. 1 based on a study of the average daily figures made under his direction. Gratitude must also be expressed to Mr. A. W. Hampton for preparing the figures from the writer's drawings.

REFERENCES

ANDREWS, E. C. (1911): Erosion and its Significance. *J. Proc. Roy. Soc., N.S.W.*, *45*, 116–36.

CAMPBELL, F. B. and BAUDER, H. A. (1940): A rating-curve for determining Silt-discharge in Streams. *Trans. Am. Geophys. Union*, 1940, 603–7.

CUMBERLAND, K. B. (1945): "Soil Erosion in New Zealand." Soil Conservation and Rivers Control Council, Wellington.

FURKETT, F. (1933): Discussion (p. 190) appended to Woods, J. (1933), q.v.

GILBERT, G. K. (1884): The Topographic Features of Lake Shores. *U.S. Geol. Surv. 5th Annual Rept.*, p. 89.

HOWARD, C. S. (1942): Transportation of Mineral Matter by Surface Water. *Hydrology, Physics of the Earth*, *9*, Nat. Research Council, Washington, pp. 637–45.

INDRI, E. (1935): Sulla Determinazione della Portata Solida nei Corsi d'acqua Naturali. *Proc. 8th Nat. Congr. Waters. Padua* (cited by Straub, below).

SPEIGHT, R. (1911): A Preliminary Account of the Geological Features of the Christchurch Artesian Basin. *Trans. N.Z. Inst.*, *43*, 420–36.

——— (1928): Geological Features of the Waimakariri Basin. *Rec. Cant. Mus.*, *2*, 199–229.

STRAUB, L. G. (1942): Mechanics of Rivers. *Hydrology, Physics of the Earth*, *9*, Nat. Research Council, Washington, pp. 614–635, esp. pp. 626–29.

WOOD, J. (1933): Waimakariri River Control. *Proc. N.Z. Soc. Civil Engrs.*, 1933, pp. 155–77, with discussion recorded in later pages.

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NOTES ON THE LATER GEOLOGIC HISTORY OF THE WELLINGTON PENINSULA

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Summary

The geological episodes, including faults, since the Wellington fault are on the little evidence available arranged in sequence.

INTRODUCTION

DURING the winter of 1945 the proposed course of the thirty-six-mile water-pipe line from the Hutt River above its junction with the Pakuratahi River to Karori Reservoir was investigated for evidence of crustal instability dangerous to such a structure. In order to obtain a general picture of the geologic history of the area a brief survey was made of the area between Hutt Valley and the west coast. Detailed work was confined to a few critical localities. In addition to information relating specifically to the course of the pipe-line, some general impressions of the area are recorded in the form of a hypothesis. This area has been previously described by Professor C. A. Cotton, the most important paper being "Notes on Wellington Physiography."(1)

GENERAL GEOLOGY

The area is bounded on the east by the Hutt Valley depression and on the west by a fault coast(2). The Wellington Fault forms the west boundary of the Hutt Valley and continues northward to cross the Pakuratahi River about a quarter of a mile above its junction with the Hutt River. The principal fracture-lines strike, in general, slightly east of north, and some transverse ones undoubtedly exist.

The area as a whole is a maturely dissected surface eroded in complexly folded greywacke. The hills, which rise to a maximum elevation of about 1,500 ft., have smooth outlines. The larger valleys are broad and flat, and many of them are thought to have been guided by old fracture-lines. Pleistocene and Recent sediments floor many of the hollows and valleys.

Rejuvenation of this surface, however, initiated a new cycle in which were carved the younger valleys of the Ngahauranga and Kaiwarra. Drowned topography, as at Porirua and Pahautanui, indicates recent rise of the sea-level. Emergence is indicated by the elevated wave-cut platforms at Plimmerton and Port Nicholson.

THE WELLINGTON FAULT

Though a casual inspection of the scarp of the Wellington Fault suggests the major movement along it was comparatively recent, such movement may be as old as late Pliocene. This is indicated by the width of the wave-cut platform fronting the scarp and the cliffing at the inner margin of the platform; cliffs about 100 ft. high back a 4-chain platform.

Thrusting along this fault-zone is evidenced by the great width of intense crushing and distortion, measurable in hundreds of feet, at the Western Hutt Road and New Haywards Road junction, and also at Horokiwi Quarry.

The Kaitoke Fault, presently referred to, probably indicates renewed movement along this fault zone.

OLD FRACTURE LINES

The drainage in many places within this area is considered to be subsequent on old fracture lines, some of which are shown in Fig. 1. The original scarps of these fractures are no longer in evidence. The dissection suggests a considerable lapse of time since the last movements, but they may be as young as the last movement on the Wellington Fault. These fractures form an intersecting pattern, and the valleys that follow them are characteristically long and straight, as, for example, Duck Creek.

The only movements in historic times(3) affected the Wellington district as a whole and did not produce severe localized deformation except along the Wairarapa Fault. From the point of view of human affairs, the district is not considered as dangerously unstable. The view of those who consider that the movements in recent geological times are continuations of the Kaikoura orogeny is shared by the author.

RECENT FAULTS

Definite evidence of recent faulting was seen at only three places within this area—namely, the Kaitoke Fault, the Ohariu Fault, and the Quartz Creek Fault.

The Kaitoke Fault (Fig. 1) extends (as far as the writer's observations were carried) south-westward for about four miles from a point about half-way between Kaitoke Railway-station and the Wellington Fault. It is parallel with the Wellington Fault and is easily identified in the field because the original scarp, with about 4 ft. downthrow to the south-east, forms a prominent feature across the flat paddocks. The small amount of dissection of the scarp indicates that this is a recent movement.

The Ohariu Fault (Figs. 1 and 2) follows the Ohariu Valley about two miles north-west of Johnsonville. It has a downthrow to the east of about 4 ft. and is at about the same stage of dissection as the Kaitoke Fault. It was mapped by McKay(4) as an active fault, but the only recent description is that by A. M. Quennell (M.S.).

The Quartz Creek Fault (Fig. 1) follows the east side of the Kahao Valley, on the north side of Pahautanui Inlet. This, like the Ohariu Fault and the Kaitoke Fault, has been known for some time. It is very similar to the Ohariu Fault and, in fact, the suggestion has been made that they are on the same line of fracture, parallel with the coast.

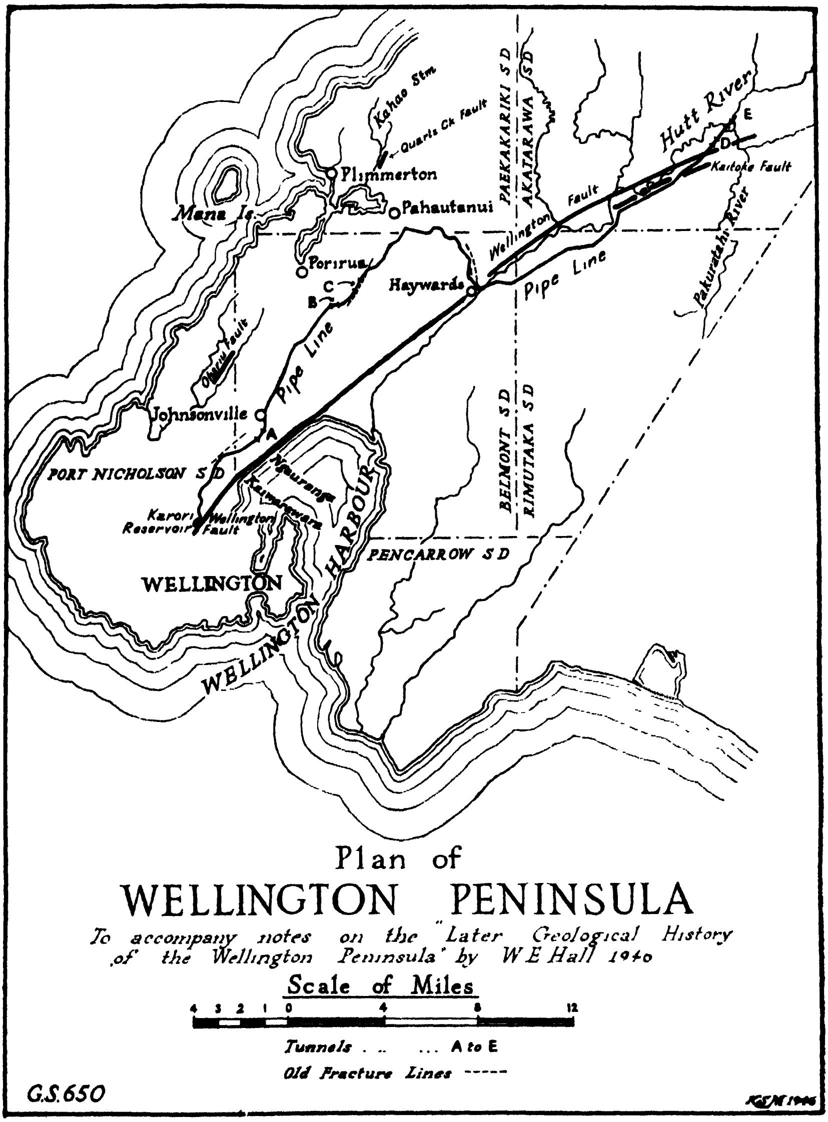

Kahao Stm
Quartz Ck Fault
Plimmerton
Pahautanui
Mana Is.
Porirua
C
B
Haywards
PAEKAKARIKI S D
AKATARAWA S D
Hutt River
E
D
Kaitoke Fault
Fault
Wellington
Pipe Line
Pakuratahi River
Ohariu Fault
Pipe Line
Johnsonville
A
PORT NICHOLSON S D
Ngauranga
Kaiwarawara
Karori Reservoir
Wellington Fault
BELMONT S D
RIMUTAKA S D
HARBOUR
PENCARROW S D
WELLINGTON
WELLINGTON
Plan of
WELLINGTON PENINSULA
To accompany notes on the "Later Geological History of the Wellington Peninsula" by W E Hall 1940
Scale of Miles
4 3 2 1 0 4 8 12
Tunnels . .. ... A to E
Old Fracture Lines -----
G.S.650

FIG. 1

GEOLOGIC HISTORY HYPOTHESIS

The geologic history of the area under consideration has been thoroughly investigated only so far as it bears on the course of the proposed pipe-line. General impressions gained from this work, however, are presented as a hypothesis which may serve as a starting-point for future work of a more comprehensive nature :—

(1) *Middle or Late Pliocene.*—Last large movements on all faults in the area, including the Wellington Fault :
(2) *Plio-Pleistocene.*—Regional depression :
(3) *Plio-Pleistocene.*—Deep alluviation :
(4) *Middle Pleistocene.*—Regional uplift :
(5) *Middle Pleistocene.*—Much of the alluvium removed, except remnants in wide valleys such as the Hutt and Porirua, together with deep, narrow gorge-cutting in small valleys such as Ngahauranga and Kaiwarra (this last being supplemented by capture, *vide* Cotton) :

FIG. 2.—Looking down Ohariu Valley from two miles north-west of Johnsonville at Recent fault trace showing in centre.

(6) *Recent.*—Small up-and-down movements—*e.g.*, 1855—and small faults such as Kaitoke, Ohariu, and Quartz Creek.
(7) The small high-level basins of deposition, such as at Johnsonville and Haywards. These deposits may have been laid down during the time of regional depression (Plio-Pleistocene) and later considerably cut away following the regional uplift (Middle Pleistocene).

REFERENCES

(1) COTTON, C. A. (1911): *Trans. and Proc. of the N.Z. Inst.*, *44*, 245–65.
(2) ——— (1916): Fault Coasts in New Zealand. *Geog. Review*, *1*, 20–47.
(3) ——— (1921): How Long will Wellington escape Destruction by Earthquake? *N.Z. J. Sci. & Tech.*, *3*, 229–31.
(4) McKAY, A. (1892): *Rep. Geol. Explor.*, 1–28.

WATER-SUPPLY FOR COASTAL AREA BETWEEN FOXTON AND LEVIN

By W. E. HALL, Geological Survey, Department of Scientific and Industrial Research

[*Received for publication, 3rd April, 1946*]

Summary

The coastal area between Foxton and Levin is shown to be provided with flowing rivers, shallow surface water, and at least two artesian water strata but these are at present used inefficiently.

INTRODUCTION

THE District Engineer, Public Works Department, requested an investigation of the water resources of the Oturoa Soldiers' Settlement and environs. This work was carried out during the week ending 22nd February, 1946, and involved a brief examination of the coastal area between Foxton and Levin.

Most of the area is little above sea-level and is essentially flat, except for the slightly convex cross-profile of the lower Manawatu River course and the numerous patches of fixed sand-dunes.

In the coastal strip between Foxton and Levin the evidence shows two persistent water-bearing strata, both of which are artesian. The upper is non-flowing, but the water rises high in the wells, and in the lower the water usually flows from the wells. Both these strata should produce a large quantity of water over a considerable area, but the lower is expected to be more widespread. In addition, it is possible to get water by tapping the shallow water-table at approximately 5 ft. to 30 ft. on any flat part of the area. This water, however, is generally contaminated. The lower Manawatu River water is unsuitable because it is brackish in summer. The Ohau River is being used for the Levin water-supply.

NATURE OF EVIDENCE

Drilling information throughout this area has not, as far as the writer could ascertain, been scientifically recorded. Records are not usually made of any of the following: exact location, elevation, method, cores or cuttings, casing, drilling, static level, pumping, drawdown, and analyses of waters. Drillers' logs are available for only a small percentage of the wells. Records of screening, packers, cement, and other valuable data do not exist. For information concerning the majority of the wells in this area one must rely on the recollections of the driller or, in his absence, those of the person for whom the well was put down. In view of the above, only general statements can be made at the present time.

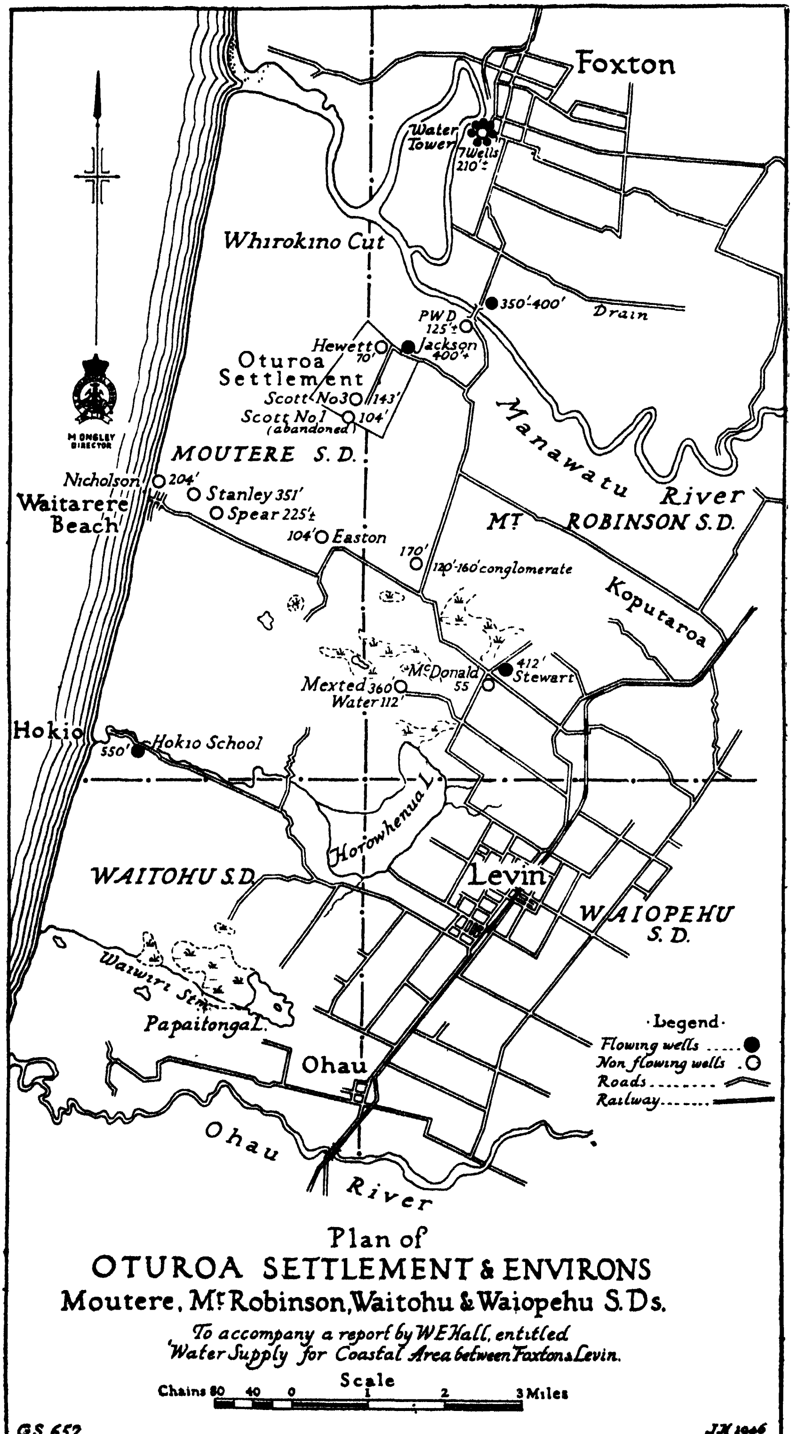

Foxton
Water Tower
7 Wells 210'±
Whirokino Cut
350'-400'
Drain
PWD 125'±
Hewett 70'
Jackson 400'+
Oturoa Settlement
Scott No3 143'
Scott No1 104' (abandoned)
Manawatu River
MOUTERE S.D.
Nicholson 204'
Stanley 351'
Spear 225'±
Waitarere Beach
104' Easton
170'
120'-160' conglomerate
MT ROBINSON S.D.
Koputaroa
McDonald 55
412' Stewart
Mexted 360'
Water 112'
Hokio
550'
Hokio School
Horowhenua L.
WAITOHU S.D.
Levin
WAIOPEHU S.D.
Waiwiri Stm
Papaitonga L.
Ohau
Ohau River
·Legend·
Flowing wells
Non flowing wells
Roads
Railway
Plan of
OTUROA SETTLEMENT & ENVIRONS
Moutere, Mt Robinson, Waitohu & Waiopehu S.Ds.
To accompany a report by W.E. Hall, entitled 'Water Supply for Coastal Area between Foxton & Levin.
Scale
Chains 80 40 0 1 2 3 Miles
G.S. 652
J.H. 1946

FIG. 1.

UPPER WATER STRATUM

Some of the wells that reach this stratum are approximately located on the attached plan (Fig. 1). All, as far as could be ascertained, are on the pump. It is by no means certain that this is strictly a single aquifer. It varies from about 50 ft. to over 200 ft. below the surface in different parts of the area.

The water sand is overlain by what is variously called "papa," "shale," or "clay." According to the logs and oral reports, this material ranges from a few inches to about 20 ft. in thickness and is in some places interfingered with fine sand; no sample of it was obtainable. Some shaly material outcropping along the banks of the Manawatu River at the east end of the Whirokino Cut is almost flat. It grades laterally into fine sand, and was found by Dr. H. J. Finlay to consist essentially of tuff. It seems likely that similar lenses at approximately one horizon may be the so-called "papa."

The water sand was examined and graded by Dr. C. O. Hutton and found to consist essentially of sub-rounded andesitic material of fine-sand grade, only 5 per cent. being of finer grade. It is therefore very porous and easily screenable.

Generally, initial production from this sand is good, but sometimes trouble follows with sanding up. In fact, it seems usual to drill only a very few feet below the casing (set in the "papa") on this account. With this procedure an initial production of 5 g.p.m. is normally expected. The Scott No. 1 well (see plan) pumped 5 g.p.m. at 100 ft. for many years; the Easton well at 104 ft. (2 in. casing 99 ft.) pumps 7 g.p.m.; the Scott No. 3 well has 53 ft. of open hole below the casing set in "papa" at 94 ft., and the initial production on the pump was 7 g.p.m.; but sanding up has been a constant source of trouble. Many other sketchy well histories are obtainable from this area, but none indicates that the sanding-up of this upper horizon has been adequately handled.

LOWER FLOWING WATER HORIZON

Within the area concerned four quite good flowing wells were noted (see Fig. 1). At the south end of the Foxton Viaduct there is an old well which is flowing between 5 g.p.m. and 10 g.p.m. The Jackson well, at the north-east corner of the Oturoa Settlement, maintains a good flow from over 400 ft. One well on the Stewart farm has good flowing water from 412 ft., and an old well at the Hokio Boys' School still has a good flow from 550 ft.

In addition to the above information, the writer was informed that a number of flowing wells in the vicinity of Koputaroa produce at from 50 ft. to 100 ft., and the flowing wells that supply the Foxton water-tower produce 40 + g.p.m. from 210 ft.

In the absence of well samples, and in face of such scanty information, it is not certain that there is only one flowing horizon. Flowing water, however, is clearly very widespread in this area. Further, a gradual deepening of the flowing horizons to the south-west is apparent.

Deep flowing horizons may be present as at Palmerston North, where, according to drillers' information, one was encountered between 220 ft. and 280 ft. and another between 330 ft. and 400 ft., the lower being much more productive and ranging up to 100 g.p.m. through 4 in. casing.

According to scanty records, the material of the flowing aquifers appears to be variable—it may be fine or coarse sand, or gravel.

CONCLUSIONS

In the general area of the Oturoa Settlement the water-table is always close to the surface and locally intersects it in numerous places, where small swamps are choked with rotting vegetation. For this reason, surface wells 10 ft. to 30 ft. deep are generally contaminated and the water is not suitable for human consumption.

The variation in depth of the upper water stratum could be partly accounted for if the overlying " papa " were lenticular. The " papa " may have been laid down in lakes and stream backwaters during a considerable length of time. According to this theory, it would be possible to drill through alternating shale and sand lenses with different conditions in each as to water analyses, amount of water, and character of sand. The fineness of the producing sand of this stratum has been the cause of endless trouble in the past, and has necessitated the bit penetrating as little as possible below the casing to avoid caving and sanding up. With screening, cementing, packing, and other well-established methods it should be possible to utilize the full thickness of any producing beds and even to tap several in a single well. From a single sample, mentioned earlier, the producing sand appears to be in the fine-sand grade and is thus easily screenable. In fact, no well should be drilled into such material without careful consideration of screening.

There appears to be considerable water in this general stratum and there is no reason why a good supply should not be found anywhere in the area concerned. It is possible, however, that, owing to local thinning or fissuring of the overlying " papa," cementing of the sand, or other causes, trouble might be encountered. In such cases an offset well a chain or two away might be necessary. In the case of wells that have developed trouble with sanding up, especially those with a considerable open hole such as Scott No. 3, no permanent solution of the trouble is likely other than sinking a new well with proper precautions to prevent a recurrence of the difficulty. If an additional string of casing was run to overcome this trouble, the danger of pollution due to defects in the old casing and other causes would remain.

The evidence from artesian wells cited above indicates that good artesian water is to be had anywhere in this coastal belt. Considering the nature of artesian aquifers and the fact that such water is already utilized as far north as Foxton and as far south as Hokio Stream (the limits of the writer's investigations), it is reasonable to infer that artesian strata will extend considerably beyond the area concerned. The depth of artesian water has been shown to vary considerably, with a general deepening to the south-west. In the neighbourhood of the Oturoa Settlement it is probably of the order of 450 ft. Deeper artesian horizons are to be expected here.

An attempt was made to determine the stratigraphic interval between the upper and the lower water strata. It appears that the well at the Hokio Boys' School encountered a good flow of water just below 5 ft. of " papa " at 335 ft. This may be the upper stratum, and, if so, the interval in this locality is about 215 ft.

RECOMMENDATIONS

General.—It is recommended that a fully recorded test hole be sunk in this area and that, according to the conditions encountered, it be put down 500 ft. to 800 ft.

In view of the importance of ground water, it is strongly recommended that accurate and complete records should be made in future at the actual time of drilling, and that these records should include the following: a careful log, supplemented, if possible, by cores or cuttings; casing and screen, &c., record; exact location; type of drilling rig; type of drilling encountered; pump or flow; water analyses from each sand; initial production; drawdown; and temperatures, &c.

Conservation.—Ground-water supplies are not inexhaustible, and, further, fluctuate from season to season. If up-to-date drilling methods are adopted, even though the initial expense would be greater, a big demand would develop for wells, as shortage of water in summer is probably the biggest difficulty of most of the farmers. Also, the water needs of future industrial expansion must not be overlooked. The withdrawal of large quantities of water will lower the static level, and this applies equally to deep horizons, which, when once depleted, are harder to restore than shallow ones. Shallow and deep alike ultimately depend on rain-water. It is recommended that some form of conservation control be instituted and that only sufficient water to meet requirements be drawn off at any time, even in winter.

Pollution.—The Scott No. 1 well, after pumping about 5 g.p.m. for a number of years, suddenly became polluted. This suggests casing trouble due to corrosive water outside the upper part of the hole. If analyses were taken of all waters encountered, precautions (such as cementing or special pipe at the danger zones) could be taken against such occurrences. The loss of a single well in this manner is far less important than the fact that a large area of the good water is likely to be polluted.

Wells that are no longer needed and are just left to flow unrestricted (there are several in this area) are liable to cause pollution sooner or later, and it is recommended that all abandoned wells should be properly sealed

Wells located in cow-yards and near sewage are liable to pollution. It is recommended that the acceptable distance of 50 ft. from any source of pollution should be insisted upon.

EARTHQUAKES IN NEW ZEALAND DURING THE YEAR 1945

By R. C. HAYES, Dominion Observatory, Department of Scientific and Industrial Research

[*Received for publication, 11th February, 1946*]

THE accompanying map shows the epicentres of earthquakes in the New Zealand region during the year 1945. Shocks with origins deeper than

FIG. 1.

normal are indicated by special symbols. Accuracy of epicentre determination is also indicated.

The two inset maps show the approximate isoseismals of two of the most notable shocks during the year.

Some additional particulars of the earthquakes whose epicentres are shown on the main map are given below :—

No.	Date and Time (G.M.T.).*				Maximum Felt Intensity (M.-M.).	No.	Date and Time (G.M.T.).*				Maximum Felt Intensity (M.-M.).
	1945	d.	h.	m.			1945	d.	h.	m.	
1	Jan. ..	1	01	08·1	V	51	May ..	19	02	41·6	III
2	„ ..	2	04	56·8	V	52	„ ..	20	14	06ca	II
3	„ ..	3	14	35·9	..	53	„ ..	20	14	25ca	II+
4	„ ..	4	23	41·3	..	54	„ ..	21	18	00·4	II
5	„ ..	10	01	00·7	..	55	„ ..	26	16	50·7	V
6	„ ..	13	13	28·1	..	56	„ ..	28	03	10·6	..
7	„ ..	14	21	08·0	IV	57	June ..	3	17	20·3	..
8	„ ..	16	03	58·5	..	58	„ ..	6	03	18·9	..
9	„ ..	16	15	30ca	III?	59	„ ..	6	23	53·4	..
10	„ ..	18	18	01·3	..	60	„ ..	7	03	42·4	V
11	„ ..	19	20	23ca	I	61	„ ..	7	03	59·3	II
12	„ ..	27	22	38·5	..	62	„ ..	8	09	06·5	II
13	Feb. ..	1	12	20·4	..	63	„ ..	9	07	48·2	..
14	„ ..	14	16	20·2	II	64	„ ..	10	06	40ca	II
15	„ ..	18	13	31·1	IV	65	„ ..	14	17	53·6	IV
16	„ ..	18	16	35ca	II	66	„ ..	14	18	25ca	IV
17	„ ..	24	04	21·3	..	67	„ ..	14	22	43·2	IV
18	„ ..	24	07	32·1	..	68	„ ..	17	19	59ca	I
19	„ ..	25	02	07·3	..	69	„ ..	19	18	27·7	..
20	„ ..	25	17	11·9	..	70	„ ..	22	12	07·4	I
21	Mar. ..	7	15	31ca	I	71	„ ..	25	18	08·6	IV
22	„ ..	9	15	21·5	II	72	„ ..	25	18	57ca	III
23	„ ..	9	19	11·8	I	73	„ ..	29	11	19·4	..
24	„ ..	11	19	22·2	IV	74	July ..	2	00	07·0	..
25	„ ..	12	18	51·8	II	75	„ ..	5	21	18·4	..
26	„ ..	12	22	02·1	II	76	„ ..	6	15	52·8	IV
27	„ ..	12	23	49·5	IV	77	„ ..	8	18	02·4	II
28	„ ..	15	20	26·7	III	78	„ ..	9	02	53·1	..
29	„ ..	18	09	02·3	..	79	„ ..	12	00	45·4	IV
30	„ ..	18	18	22·6	III	80	„ ..	19	14	35ca	II?
31	„ ..	19	16	34·6	IV	81	„ ..	20	07	35ca	II?
32	„ ..	19	17	45·3	IV	82	„ ..	20	11	20ca	II?
33	„ ..	24	12	05·0	..	83	„ ..	20	12	35ca	II?
34	„ ..	26	16	52ca	II	84	„ ..	20	12	59ca	IV
35	„ ..	31	10	29·8ca	I	85	„ ..	20	13	50ca	IV
36	Apr. ..	1	00	44·4	..	86	„ ..	20	14	07ca	IV
37	„ ..	7	06	30ca	II?	87	„ ..	20	14	39ca	V
38	„ ..	8	21	11·1	..	88	„ ..	20	23	56·8	..
39	„ ..	17	09	13·3	II	89	„ ..	24	02	18·3	..
40	„ ..	23	11	04·4	IV	90	„ ..	24	10	55·5	III
41	„ ..	24	04	43·9	..	91	„ ..	27	13	55·7	IV
42	May ..	5	10	05·7	..	92	„ ..	28	14	03·5	III
43	„ ..	5	10	37·2	..	93	„ ..	30	12	30·3	II?
44	„ ..	7	09	18·8	..	94	Aug. ..	10	08	45ca	III
45	„ ..	9	16	50·6	II	95	„ ..	10	15	08·0	IV
46	„ ..	10	13	17·7	III	96	„ ..	11	03	51·5	
47	„ ..	15	17	59ca	II	97	„ ..	13	02	20·8	IV
48	„ ..	17	16	28·9	..	98	„ ..	15	14	12·9	IV
49	„ ..	17	23	56·0	..	99	„ ..	16	21	55·8	..
50	„ ..	18	09	27·8	..	100	„ ..	17	19	32·6	III

* G.M.T. (Greenwich Mean Time) is 12h. 00m. slow on New Zealand Standard Time.

No.	Date and Time (G.M.T.).*				Maximum Felt Intensity (M.-M.).	No.	Date and Time (G.M.T.).*				Maximum Felt Intensity (M.-M.).
	1945	d.	h.	m.			1945	d.	h.	m.	
101	Aug. ..	17	23	38·3	..	139	Oct. ..	5	14	56·2	III
102	,, ..	23	12	51·7	..	140	,, ..	8	10	49·2	..
103	,, ..	25	10	12·5	III	141	,, ..	12	04	18·7	IV
104	,, ..	25	10	29·7	III	142	,, ..	12	06	10ca	IV
105	,, ..	29	15	57·9	VI	143	,, ..	12	11	22·7	III
106	,, ..	29	16	27·2	III	144	,, ..	12	11	59·9	IV
107	,, ..	29	16	46·5	III	145	,, ..	12	21	05ca	IV
108	,, ..	29	19	59·5	III	146	,, ..	12	22	28·2	IV
109	,, ..	29	21	42·3	IV	147	,, ..	13	14	45·0	..
110	,, ..	29	23	55ca	III	148	,, ..	14	12	06·5	IV
111	,, ..	30	04	55·7	VI	149	,, ..	14	12	59·4	..
112	,, ..	30	05	05ca	III	150	,, ..	16	04	19·5	..
113	,, ..	30	06	00ca	III	151	,, ..	18	01	33·7	..
114	,, ..	30	07	16·0	III	152	,, ..	18	06	06·4	II
115	,, ..	30	07	37ca	III	153	,, ..	23	12	58·5	..
116	,, ..	30	08	48·7	IV	154	,, ..	30	18	42·9	IV
117	,, ..	30	10	25·7	VI	155	Nov. ..	5	11	19·0	..
118	,, ..	30	10	27ca	III	156	,, ..	6	09	47ca	II
119	,, ..	30	10	33·2	III	157	,, ..	9	13	40·3	..
120	,, ..	30	12	45·1	IV	158	,, ..	9	20	55·7	IV
121	,, ..	30	15	49·4	IV	159	,, ..	10	11	46ca	III
122	,, ..	30	19	04·6	IV	160	,, ..	10	20	57·3	..
123	Sept. ..	1	22	44·4	V	161	,, ..	12	12	52·5	..
124	,, ..	4	17	14·3	V	162	,, ..	15	20	22·9	..
125	,, ..	10	12	21·0	II	163	,, ..	15	22	37·5	..
126	,, ..	14	04	04·4	III	164	,, ..	16	06	47·5	III
127	,, ..	15	18	49·9	IV	165	,, ..	17	11	14·2	..
128	,, ..	15	19	01·9	III	166	,, ..	27	00	08·8	..
129	,, ..	17	03	39·4	IV	167	Dec. ..	8	00	07·4	..
130	,, ..	19	09	34·4	..	168	,, ..	12	02	38ca	III
131	,, ..	22	15	13ca	II	169	,, ..	17	09	00ca	III
132	,, ..	22	15	40ca	IV	170	,, ..	17	21	41·4	IV
133	,, ..	22	16	20·7	..	171	,, ..	19	17	43·9	II
134	,, ..	23	04	15ca	IV	172	,, ..	22	16	55·3	III
135	,, ..	26	09	38·0	III	173	,, ..	26	13	56·0	II
136	,, ..	26	18	46·2	III	174	,, ..	28	06	31·8	III
137	,, ..	27	01	50·5	..	175	,, ..	28	09	15ca	III
138	Oct. ..	5	12	59ca	II	176	,, ..	30	07	07·4	II

* G.M.T. (Greenwich Mean Time) is 12h. 00m. slow on New Zealand Standard Time.

The following earthquakes, tabulated above, were centred outside the boundary of the map: Nos. 36, 123, 124.

OREPUKI COALFIELD, SOUTHLAND

By R. W. WILLETT, Geological Survey, Department of Scientific and Industrial Research

[*Received for publication, 6th May, 1946*]

Summary

The area described lies on the south-west coast of Southland about 43 miles west of Invercargill. The coalfield occupies 4 square miles adjacent to the township of Orepuki, and has been worked intermittently since about 1882 at the shale-works and on the Waimeamea River. A total of 30,745 tons of coal has been produced since 1882. The coal ranges in thickness from 8 ft. to 26 ft., overlain by 9 in. to 4 ft. 9 in. of oil-shale, and dips about 1 in 4. The coal-measures are separated from the basal igneous complex by a few feet of sandstone and are overlain by fossiliferous beds of Whaingaroan age. Plans of past and present workings are presented. The structure of the field, apart from areas near the margins, is not clear, but there is sufficient evidence to suggest that it is much faulted. Considerable drilling would be required to prove the field before any major coal-mining venture could be undertaken. The coal is a lignite of just over 9,000 B.Th.U. per pound.

PREVIOUS WORK

THE area covered by the Orepuki Coalfield has been already described and geologic conditions discussed by Messrs. Willett and Wellman (1940) in a report dealing with the Orepuki oil-shale, in which mention was merely made of the occurrence of coal underlying the oil-shale. An account of all the previous geological reports on this area is also presented in that report.

In 1882 the Orepuki Coal and Shale Co. began operations in the vicinity of the now disused shale-works, and about 1894 abandoned all operations (plans of these workings are shown in Fig. 5, Willett and Wellman, 1940, p. 98B). The earlier workings covered a small area and were operated from 1882 to 1890 and produced 4,728 tons of coal. About 1887 this mine had practically ceased work. Only a small amount of coal was being mined, and that was later recovered from a small opencast for local consumption. The low prices and lack of market were stated as reasons for cessation of work. In 1891 a fresh start was made on the east of the Taunoa Creek (see Fig. 5, Willett and Wellman, 1940, p. 98B), where dip workings were opened up and operated until 1894. Coal-production was small, being 655 tons. The mine ceased operation largely because of the lack of market. Hector (1894) described this mine in his report on the Orepuki area.

The Mines Inspector's report for 1893 states that the roof was composed of soft laminated rocks over 4 ft. of oil-shale, 7 ft. to 8 ft. of coal with odd bands of oil-shale, 5 ft. of good coal, and 6 in. of oil-shale. The nature of the floor below the last layer of oil-shale is not given. The rights of this area were taken over by the New Zealand Collieries, Railway, and Oil Syndicate, Ltd., in 1899, and an extensive boring and prospecting programme carried out. A new mine was then developed to the east of the old 1882–90 workings which was operated until 1903, producing 18,988 tons of coal together with 14,422 tons of oil-shale. The margins of the coal-measures having been reached, mining difficulties resulting from the faulted nature of the country and the bad roof brought about the cessation of activity on the 17th July, 1903.

On the northern margin of the coalfield lies the second area where coal was mined extensively and which is to-day the scene of renewed mining activity. On the banks of the Waimeamea River, 22 chains west-north-west of the present coal-mine, opencast working started in 1885 and continued

intermittently until 1904, producing 156 tons of coal. In 1917 these opencast workings were recommenced and were bought out in 1918 by the New Zealand Coal and Oil Co.; a new mine was commenced about 8 chains south-east of the old opencast. These workings were fairly extensive (see Fig. 1), but after producing 10,003 tons of coal ceased operations in 1922. The opencast that operated from 1917 to 1918 produced 1,983 tons.

In 1932, Hennessey's opencast workings were commenced about 10 chains upstream from the old mine on the banks of the Waimeamea River. These operations were carried on in a small way until the end of 1943, and produced in all 2,252½ tons. Early in 1944 the Waimeamea Coal Co. commenced underground operations immediately adjacent to the opencast workings that had just ceased, driving south-south-east along the strike of the coal (see Fig. 1). To the end of 1944 this mine had produced 914 tons of coal.

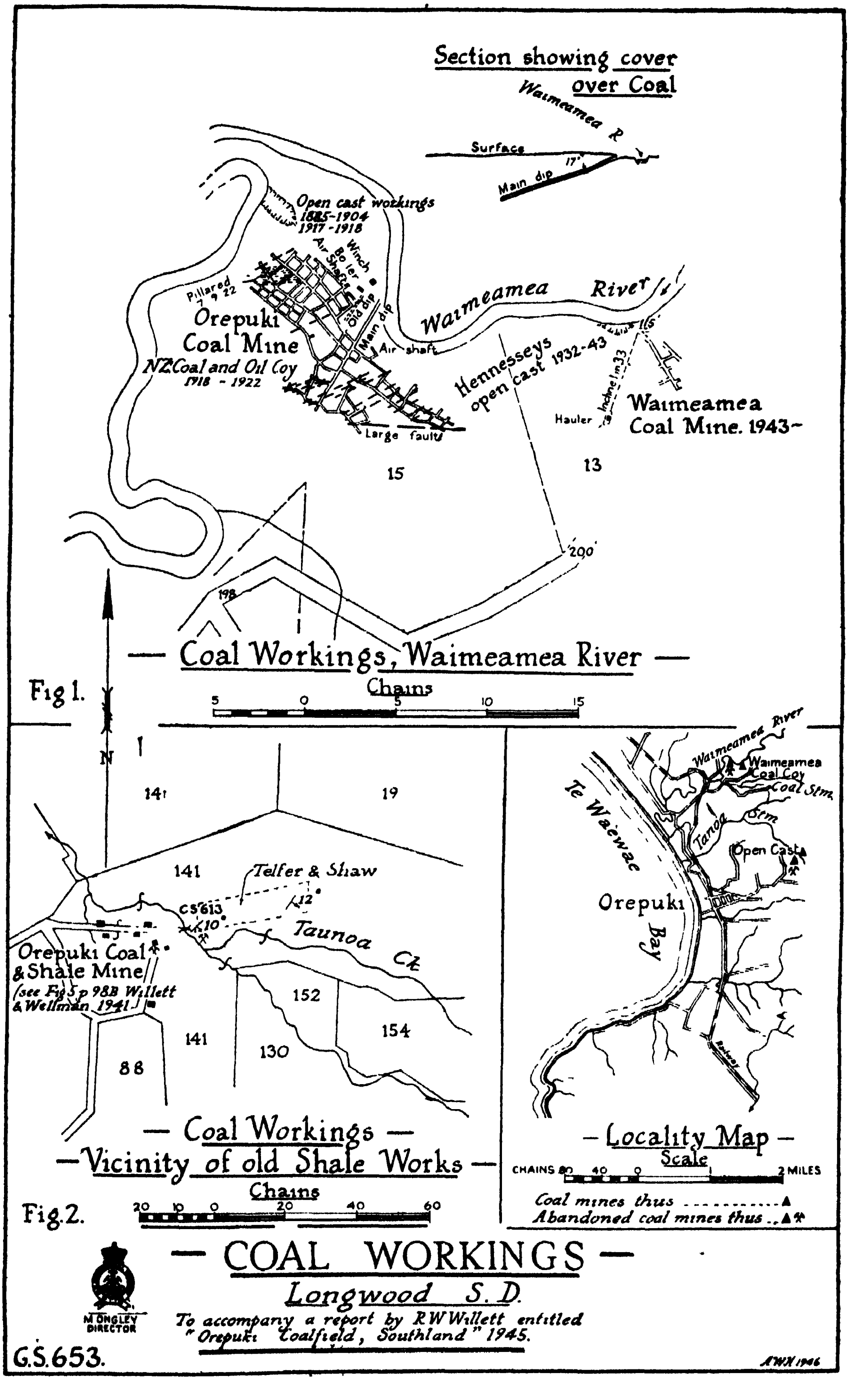
During 1944 a small opencast mine was opened up immediately east of the site of the shale-works (see Fig. 2), the overburden, consisting of old tailings and gravels, being removed by sluicing, and the coal hewn by hand. A thickness of about 5 ft. is being worked.

Since the commencement of coal-winning operations in the Orepuki district the area adjacent to the shale-works has yielded 24,437 tons, and that near the Waimeamea River 15,308½ tons, making in all a total of 39,745½ tons since 1882.

GENERAL GEOLOGY

The geology and topography of the Orepuki district is fully discussed by Willett and Wellman (1940) in a report on the Orepuki oil-shale deposits. At present practically nothing can be added to that discussion. The examination of further mudstone samples has, however, placed the lowest marine beds in the area as Whaingaroan (Dr. H. J. Finlay, pers. com.), which places the coal-measures immediately pre-Whaingaroan, and not Duntroonian as stated in the report on the oil-shale (1941, p. 87B).

The coal-measures occur at the base of the Tertiary sequence in this area, and the main coal-seam at the base of the measures, which are about 150 ft. thick, ranges from 5 ft. to 26 ft. The coal-seam is separated from the granitic basement rock by 2 ft. to 4 ft. of sandstone and is overlain by 8 in. to 4 ft. 6 in. of oil-shale. Near the shale-works site, Hector (1894) described two coal-seams, the upper, 5 ft. thick, separated from the lower by 4 ft. of fireclay. The lower seam contained 8 in. of interbedded oil-shale near the top. These sections were described from a new mine on the east side of the Taunoa Creek which operated from 1891 to 1894. Hector (1894, p. 41) considered that from a comparison of these two sections the coal thickened towards the dip, while the oil-shale seemed to decrease in thickness and value. Hector also stated that the quality of the lower seam was good of its kind, being compact and hard with a good cleavage and conchoidal fracture and the joints covered with films of pyrites. The coal in this area dips to the south-south-east at 10° to 15°. This area, adjacent to the shale-works site is separated from the main coalfield by a buried granitic ridge on the coastal or westward side of which the coal-measures dip to the west-south-west at 15°. Along a line running north-west of the shale-works four holes were drilled for the New Zealand Coal and Oil Co. in its search for a new shale area, and these showed that the coal-measures ranged in thickness from 94 ft. to 150 ft. and contained several thin seams of coal above the main seam, the latter being up to 26½ ft. thick and generally near the top of a thin seam of interbedded shale. The main coal-seam always underlies the main oil-shale seam, though some of the logs reveal thin coal and shale seams interbedded within clays of the upper part of the measures. In the deepest hole, about 24 chains north-north-west of the shale-works, the main



Section showing cover over Coal
Waimeamea R
Surface
17°
Main dip
Open cast workings 1885-1904 1917-1918
Winch
Boiler
Air Shaft
Old dip
Main dip
Pillared 7 9 22
Orepuki Coal Mine
NZ Coal and Oil Coy 1918 - 1922
Air shaft
Large fault
Waimeamea River
Hennesseys open cast 1932-43
Incline 1 in 33
Hauler
Waimeamea Coal Mine. 1943-
15
13
200
198
— Coal Workings, Waimeamea River —
Chains
Fig 1.
N
141
19
141
Telfer & Shaw
CS 613
12
10
Tauno a Ck
Orepuki Coal & Shale Mine
(see Fig 5 p 98B Willett & Wellman 1941)
152
154
141
130
88
— Coal Workings —
—Vicinity of old Shale Works —
Chains
Fig.2.
Waimeamea River
Waimeamea Coal Coy
Coal Stm
Tanoa Stm
Open Cast
Te Waewae
Orepuki
Bay
Railway
— Locality Map —
Scale
CHAINS
2 MILES
Coal mines thus
Abandoned coal mines thus
— COAL WORKINGS —
Longwood S. D.
To accompany a report by R W Willett entitled "Orepuki Coalfield, Southland" 1945.
M ONGLEY DIRECTOR
G.S.653.

FIGS. 1 AND 2.

coal-seam is 11 ft. thick at a depth of 483 ft. from the surface and appears to vary greatly. The thickest coal encountered is in another hole at 384 ft., where 26 ft. was found split into two seams of 11 ft. and 15 ft. by 1 ft. of oil-shale. The line of holes was oblique to the direction of dip, but all information indicated that the measures are dipping about 1 in 4 westward. The coal-measures do not outcrop on the coast. Sections illustrating the possible structure are presented by Willett and Wellman (1941). The present opencast workings in the shale-works area reveal that the upper part of the 10 ft. seam contains thin interbedded shale seams up to 6 in. thick. The presence of the oil-shale in this coal probably accounts for the sulphur content being higher than that from the Waimeamea Coal-mine. Although the 6 in. seam of oil-shale was rejected in sampling, the thinner streaks were included.

In the northern part of the coalfield the geologic conditions are similar, although along the Waimeamea River the oil-shale is only 8 in. thick and rests directly upon the main 12 ft. coal-seam. Overlying the shale and coal is a bedded carbonaceous mudstone. The coal-seam dips about 15° to the south-south-west and crops out at several points along the Waimeamea River between the present coal-mine and the old opencast workings.

STRUCTURE

Because of the lack of outcrops of the coal-measures, little can be said about the structure of the area. Willett and Wellman (1941, p. 90B) discussed the probable structure of the area and stressed the lack of information, but it is evident from the little information available that the field is complicated. The old reports of the mines all mention the presence of faults that have affected the working of the mines to a greater or less degree. The mine plans of the Orepuki Shale and Coal Mine and the Orepuki Mine on the Waimeamea both show numerous faults, and the working of the latter was terminated by a large fault. On the evidence of the past workings, any further mining operations must expect numerous faults, some seriously affecting the coal-seam.

PRESENT OPERATIONS

The Waimeamea Coal-mine is situated on the south bank of the Waimeamea River about 2 miles north-north-east of Orepuki and about 14 chains east of the original Orepuki Coal-mine which was opened down-stream. The present mine was opened at the end of 1943 in Section 13, Block 3, of the Longwood Survey District.

The coal-seam is 10 ft. to 15 ft. thick and strikes 145° with a dip of 10° to the south-west. It is overlain by a soft-bedded carbonaceous mudstone which is separated from the coal-seam by 8 in. of oil-shale. Thin bands of oil-shale were noted within the coal itself. The bottom of the coal could not be seen, but it is likely to be similar to that noted elsewhere in the area—*i.e.*, about 4 ft. of hard sandstone resting directly upon the basement igneous rocks.

The main trucking level has been driven along the strike of the seam for a distance of about 4 chains; from it three small rises branch and a short drive extends towards the dip (Fig. 1). The end of the main level encountered a fault which, on examination, appeared to have a throw greater than the seam thickness. The fault dips to the north-west at 50° and the sand below the seam is exposed by it. Further work revealed the coal in the roof. A rise driven at an oblique angle to the dip of the coal encountered what appeared to be another fault with no great throw but with the same strike and dip as the previous one; however, it proved to be the same fault.

It is apparent that the throw of the fault decreases along the strike in a north-east direction, but what it does in the opposite direction is not known. It is the manager's intention to drive through the fault in the rise and then drive along the strike of the seam parallel to the main level. It appears likely that if the main level is pushed on past the fault the coal will be encountered, as it seems to be striking obliquely to the main level beyond the fault. The work must be pushed on along the level, as there is practically no rise coal to the north-east, there being about 2 chains between the main level and the outcrop. In fact, the surface has already been reached by one rise. The level has not been pushed on far enough to enable any quantity of dip coal to be developed, and, further, the proximity of this mine to the old workings of the Orepuki Coal-mine considerably lessens the available quantity of dip coal. In the direction of the strike of the seam—namely, to the south-east—the nearest reported occurrence of coal is in Coal Creek, about 40 chains to the south-east. Between the mine and Coal Creek is a considerable unproved area, and it is towards this area that the present workings are being driven. It would be wise for the company to sink some auger holes over the ridge between the Waimeamea and Coal Creek to obtain some idea of the depth and continuity of the seam.

The workings of the Orepuki Coal-mine on the Waimeamea River were to the west of the present mine and covered an area of about 84 square chains, extending to a point within 12 chains of the present mine workings. The seam dipped at 15° to the south-west. On the plan of the old workings many small parallel faults are shown, but they seem to have had little throw and have not affected the workings at all. There is a large fault oblique to the others which appears to terminate the workings in the south-east area. In the Inspector's report for 1922 (C.–2, 1923) it is stated : "mining operations were suspended in September, 1922, because of a fault and trouble in the dip extension and in the lower levels."

It is reasonable to expect that similar faulting will be encountered in the present workings, and so far this appears to be the case with small faults of varying throw. The large fault that terminated the old workings runs east, and if it persists the present workings will have to be driven 3 chains before it is encountered. If this is so, the area of coal available is further limited, and it is thus important that the main level should be driven on to determine whether the large fault does extend eastwards as far as the present area.

Recently opencast coal workings (Fig. 2) were started on a small scale immediately east of the old shale-works. Here there is a fair area of coal, about 60 square chains, about 10 ft. thick and under a cover ranging from 2 ft. to 20 ft. This area has in the past been worked for gold, a considerable amount of the original cover having been removed, and in many places being represented by heaps of tailings. The coal formed the bottom during gold-winning operations. The overburden is at present being removed by sluicing. The coal-measures belong to the Waimeamea Series and are truncated by the overlying Orepuki Series, which represents the overburden.

At the present opencast, 5 ft. of coal is worked, the seam dipping to the south-east at 10°, the bottom not being visible. Interbedded in the coal near the top is a 6 in. seam of oil-shale. The coal was overlain by 2 ft. of heavy gravels which have been removed by sluicing. There is probably a considerable tonnage of coal (approximately 40,000 tons) available here. The overburden would be more easily stripped with machinery than with water, as the head is too small and some of the tailings are made up of extremely large boulders. Disposal of the overburden is not easy, and if any large work is contemplated, some system of back-filling will have to

be used as there is a limit to the amount of material that can be pushed towards the creek against the terrace on the north side of the property. At present, however, the size of the operation is limited by man-power and capital, so that the present methods are quite suitable. This area is one of the few places in the Orepuki area—in fact, the only large one—where coal can be worked opencast.

ANALYSES

PROXIMATE ANALYSES

(Nos. 1–8 on air-dried coal : No. 9 on coal as mined)

——	1.	2.	3.	4.	5.	6.	7.	8.	9.
Moisture (per cent.)	19·1	20·0	20·2	20·5	20·0	20·6	19·6	17·1	25·0
Volatile matter (per cent.)	37·2	29·5	30·7	32·3	32·8	31·6	32·3	30·6	39·0
Fixed carbon (per cent.)	41·1	43·4	43·9	42·8	39·8	44·2	43·9	33·1	30·0
Ash (per cent.) ..	2·6	7·1	5·2	4·4	7·4	3·6	4·2	19·2	6·0
Sulphur (per cent.) ..	..	..	..	..	..	..	..	..	4·2
Calorific value (B.Th.U. per pound)	..	..	..	..	..	..	..	..	8,440

LOSS OF MOISTURE ON AIR-DRYING

(Nos. 10–13)

——	10.	11.	12.	13.
Percentage loss .. .	5·4	4·5	4·8	4·2

PROXIMATE ANALYSES

(Nos. 10–13 on air-dried coal)

——	10.	11.	12.	13.
Moisture (per cent.)	20·6	22·8	22·8	21·9
Volatile matter (per cent.)	36·6	35·2	36·8	37·5
Fixed carbon (per cent.)	36·1	38·8	36·8	32·5
Ash (per cent.)	6·7	3·2	3·6	8·1
Sulphur (per cent.)	4·1	0·7	1·2	5·5
Calorific value (B.Th.U. per pound) ..	9,090	9,080	8,760	8,500

ULTIMATE ANALYSES

(Nos. 10–13 calculated to dry, ash-free coal)

——	10.	11.	12.	13.
Carbon (per cent.)	66·5	72·0	69·1	66·9
Hydrogen (per cent.)	4·7	4·9	5·3	5·1
Nitrogen (per cent.)	0·8	1·4	1·3	0·9
Sulphur (total), (per cent.)	5·7	0·9	1·7	7·8
Oxygen (by difference), (per cent.) ..	22·3	20·8	22·6	19·3

1. Hutton and Ulrich, p. 100, 1875.
2. Hector, *Rept. Geol. Explor. No. 22, Progress Report*, pp. 41, 1894.
3. Ditto.
4. „
5. „
6. „
7. „
8. „
9. Report on analyses of New Zealand coals, Dominion Laboratory, 1907.
10. C.S. 613 : *Coal Survey Report, C.S.R. 141*, 17th November, 1944, Telfer and Shaw opencast.
11. C.S. 614 : *Coal Survey Report, C.S.R. 141*, 17th November, 1944, Waimeamea Coal-mine.
12. C.S. 732 : Waimeamea Coal-mine, 19th July, 1945.
13. C.S. 734 Telfer and Shaw opencast, 19th July, 1945.

CONCLUSION

The Orepuki area presents reasonable prospects of developing into a coalfield of considerable extent, but before any large development is contemplated exploration of the field by drilling is imperative. What surface information there is has already been obtained, and it is now necessary to supplement this meagre knowledge by drilling. From the geological and structural point of view all that has been discussed in the oil-shale report of 1941 applies equally well to the area as a coalfield, because of the intimate association of the coal and oil-shale seams. As the history of all previous mining operations indicates the presence of serious faults that affected their working and life, structural complications must be expected. The Orepuki field and the Hokonui area between Forest Hill and Hedgehope are the only areas that have been worked in Southland whose coal is almost equal in calorific value to Ohai coal and of which there is a certain amount of information available. As the search for further coal, other than the Mataura lignite type, proceeds in Southland, both the Orepuki and Hokonui areas will no doubt receive attention. The calorific value of the Orepuki coal is 9,080, compared with 9,930 B.Th.U. per pound for Ohai coal, the latter having a lower ash, moisture, and sulphur content.

REFERENCES

HECTOR, J. (1894): Orepuki Coal and Oil Shale. *Rept. Geol. Explor. No. 22*, 39–43.

HUTTON, F. W., and ULRICH, G. H. F. (1875): "Geology and Goldfields of Otago." Mills, Dick, and Co., Dunedin.

WILLETT, R. W., and WELLMAN, H. W. (1941): The Oil-shale Deposit of Orepuki, Southland. *N.Z. J. Sci. & Tech. 22*, 84B–99B.

TESTS WITH TIMBER PRESERVATIVES IN NEW ZEALAND

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Summary

Results of tests with three water-soluble and three oil-soluble timber-preservatives are recorded. Tests include effects in retarding oviposition and larva survival using *Anobium punctatum* as the test insect, and effects of various brush coatings on survival of *Anobium* larvæ and *Calotermes brouni* in already infested timber. Various recommendations are made, and an appendix gives alternative formulæ and service records.

INTRODUCTION

THE following accounts apply to experiments carried out from 1943 to the present, and it must be clearly understood that they are small-scale tests designed merely to give an indication as to the relative merits of the various timber-preservatives available in New Zealand or on which tests have been carried out in this country. In cases where the same preservative is used in other countries in alternative solvents and carriers, the formulæ are given in an appendix to this paper, together with reports by scientific institutions as to their possibilities.

Since the present tests have been under observation for such a short time, care should be taken in the interpretation of the results in terms of permanency of any of these preservatives. Consistent results may be obtained in successive tests, and then entirely conflicting figures be obtained with the same insect and preservative in a new series of tests on the same species of timber. A great deal of work must still be carried out before an accurate knowledge is gained of all factors with a bearing on toxicity and penetration of timber-preservatives.

It is pointed out, too, that under the conditions of the following experiments there was optimum opportunity for *Anobium* to infest the wood, whereas it is often found under natural conditions that these same timbers will not be attacked by this insect till they have been seasoned for several years.

The experiments were undertaken more to evaluate the preservatives used for controlling borer infestations in buildings, rather than to test those preservatives such as Tanalith, zinc chloride, and Celcure that are suitable primarily for pre-treatment of timber prior to its use for construction purposes. However, all the preservatives discussed were tested also from the viewpoint of pre-treatment, and results are recorded in Tables I, II, and III.

TEST INSECTS

Anobium punctatum de Geer carries out the most widespread damage to seasoned timbers in New Zealand and it was selected as a test of effectiveness of the preservatives.

In the brush treatment of already infested wood, smaller tests were run using the native termite, *Calotermes brouni* Frogg.

PRESERVATIVES

These preservatives are divided into water-soluble and oil-soluble types, and the following is a list of those used :—

I. *Water-soluble Preservatives*

(*a*) *Tanalith.* —One of the Wolman salts containing sodium fluoride, sodium chromate, sodium arsenate, and dinitrophenol. It was used as a 2 per cent. water solution to give an average dry salt retention for the whole load of 0·25 lb. per cubic foot of timber. It was applied under pressure, and the treated wood, which has a uniform yellowish colour, can be stained with water, oil, or spirit stains and does not cause paint failure.

(*b*) *Celcure*, consisting of potassium dichromate, copper sulphate, acetic acid, or an acetate and, sometimes, a small amount of boric acid. It was applied under pressure as a 4° Twd. solution to give a pick-up of 5·1 gallons per cubic foot of timber. Treated wood has a greyish-blue colour and can be stained with water, oil, or spirit stains and does not cause paint failure.

(*c*) *Zinc chloride* as a 4 per cent. by weight aqueous solution to give an average dry salt retention of 1 lb. per cubic foot of timber. Treated wood is clean and can be stained with water, oil, or spirit stains and does not cause paint failure.

II. *Oil-soluble Preservatives*

(*d*) *Pentachlorphenol* :—

(1) *Boracure.* —Reported to have the following composition :—

	Per Cent. by Weight.
Pentachlorphenol	5
Pine-oil	1
Standesol	94

(2) *K. 1*, made by the writer, as follows :—

Pentachlorphenol	5
Pine-oil	1
Standesol	94

(3) *K. 2*, made by the writer, as follows :—

Pentachlorphenol	5
Linseed-oil	2
Kerosene	93

(4) *K. 3*, made by the writer, as follows :—

Pentachlorphenol	5
Pine-oil	2
Kerosene	93

(*e*) *Rentokil.*—Reported to contain chlorinated naphthas in a mixture of vegetable and mineral oils.

(*f*) *Timber Treatments*, of which the principal ingredient is zinc naphthenate in mineral oil solvents.

(*g*) *Kerosene*, lighting quality.

(*h*) *Kerosene and turpentine* as a 50 : 50 mixture.

(*i*) *Paradichlorobenzene* as a 5 per cent solution in lighting kerosene.

(*j*) *Orthodichlorobenzene* as a 5 per cent. solution in lighting kerosene.

TECHNIQUE

A. *General.*—The work was divided into two major groups, as follows :—

(1) Egg-laying experiments with *Anobium*, subdivided into—

(*a*) Compulsion tests, where each cage contained blocks treated with a single preservative.

(*b*) Preference tests, where each cage contained blocks representative of the different preservatives.

(*c*) Preference tests, where each cage contained treated and untreated blocks.

(*d*) Control experiments with untreated blocks.

(2) Larva-susceptibility tests, in which—

(*a*) *Anobium* larvæ were transferred from untreated timber to holes drilled in treated blocks. (Technique due to G. Becker in Germany.)

(*b*) *Anobium* larvæ and *Calotermes brouni* in infested timber were subjected to brush applications of preservatives.

B. *Timbers* used for egg-laying tests were well seasoned, air-dried, sapwood blocks 2 in. × 1 in. × 1 in. of the following species :—

Kahikatea (*Podocarpus dacrydioides* A. Rich.).
Rimu (*Dacrydium cupressinum* Soland.).
Insignis pine (*Pinus radiata* D. Don.).

The last species listed was the only one used in larva-transfer work, and well-seasoned, air-dried sapwood of matai (*Podocarpus spicatus* R. Br.) was employed for brush treatment with *Anobium*, and kahikatea for *Calotermes brouni*.

All blocks for any timber species were cut from the same board, and care was taken to secure samples free from knots, cracks, or other blemishes. They were kept under normal room temperatures, and examined by means of a binocular microscope to ensure that they were not already infested.

C. *Application of Preservatives to Samples.* The Tanalith samples were taken from studs 8 ft. × 4 in. × 2 in. treated on 6th February, 1945, at the pressure plant of the New Zealand Forest Products, Ltd. mill at Pinedale. They were thoroughly air-dried prior to cutting into sample blocks, to avoid the possibility of surplus liquid running over freshly cut surfaces.

The Celcure samples were pressure treated in April, 1940, at Glasgow, Scotland, by G. Gunn, the originator of the Celcure process. The timber was supplied from New Zealand by New Zealand Forest Products, Ltd.

Blocks were submerged in the zinc chloride and the oil-soluble preservatives until tests showed that they were completely penetrated. Sufficient samples were treated at one time to permit tests being carried out for five years with each preservative in order to secure results after varying periods of seasoning.

D. *Penetration of Preservatives.*—The times taken to secure complete penetration varied greatly, the oil-soluble types penetrating more readily than the water-born preservative. In general, the time ratio for treatment with zinc chloride and oil-soluble materials was 5 : 2.

Indicators for depth of penetration were dyes which were dissolved in the treating fluids, and a 10 per cent. aqueous solution of silver nitrate for the zinc chloride and pentachlorphenol preservatives. In the presence of vegetable oils the silver nitrate was not a good indicator, but in the absence of these oils it gave excellent results.

In water solutions there was often a lag of between one minute and up to twenty hours in penetration of some of the dyes behind that of the water before the blocks were completely stained, whereas in the oil solutions the same dyes penetrated as rapidly as did the solvents. Other dyes penetrated as quickly as did the water.

Retention of preservative expressed in terms of dry salt was recorded only in the case of zinc chloride and Tanalith.

E. *Recording Results.*—In egg-laying experiments, "tunnelling in" of larvæ was recorded when larvæ had bored their way into the wood to a depth so that they were hidden by frass pellets of their own making—*i.e.*, after tunnelling in approximately 2 mm. In the case of "survival" of larvæ in egg-laying experiments, the blocks for seasons 1943–44 and 1944–45 were split up after twelve months; those for 1945–46, after two months, as these tests were discontinued in February, 1946. For larva-transfer work, blocks were split up eight months after setting up experiments, the next series being set up as soon as the last in the same group had been concluded. In brush tests the numbers of *Anobium* larvæ and *Calotermes brouni* dead and alive were recorded.

EXPERIMENTS

Egg-laying Compulsion Tests with Anobium

Table I gives results of egg-laying tests where blocks treated with single preservatives were enclosed in separate cages with *Anobium* beetles sexed according to the technique adopted by Kelsey, Spiller, and Denne (1945). Five replicates for each test were used each year, and two female beetles were used for each of these replicates.

TABLE I

Preservative.	Date Blocks treated	Timber.	Number of Eggs laid.			Number of Larvæ tunnelling in			Number of Larvæ alive in		
									December,		Feb.,
			1943–44.	1944–45	1945–46.	1943 44.	1944–45	1945 46.	1944.	1945.	1946.
Tanalith	7/2/45	*P. radiata*	.	..	381		.	357	.	..	235
Celcure	?/4/40	,,	.		397	..		373	..	.	323
Zinc chloride	11/6/44	,,		355	341	.	323	328	.	119	280
,,	,,	Rimu		401	346	.	309	241	..	102	201
,,	17/5/43	Kahikatea	281	452	387	119	419	257	30	359	234
Pentachlorphenol K. 1	29/6/44	*P. radiata*		0	0	.	0	0	.	0	0
Pentachlorphenol K. 2	,,	,,	..	0	0	.	0	0		0	0
Pentachlorphenol K. 3	,,	,,	.	0	0	..	0	0	.	0	0
Pentachlorphenol K. 1	,,	Kahikatea		0	0	..	0	0	.	0	0
Pentachlorphenol K. 2	,,	,,	.	0	0		0	0	..	0	0
Pentachlorphenol K. 3	,,	,,		0	0	..	0	0	.	0	0
Kerosene	11/5/43	,,	0	7	64	0	2	23	0	2	13
Kerosene and turpentine	,,	,,	0	4	33	0	3	15	0	1	6
Paradichlorobenzene	,,	,,	0	25	171	0	19	147	0	7	56
Orthodichlorobenzene	,,	,,	0	14	285	0	11	263	0	8	70
Timber Treatments	16/11/42	,,	0	0	0	0	0	0	0	0	0
Rentokil	24/4/45	,,	.	..	0	..	.	0	..	.	0
Controls	..	,,	301	393	457	285	362	417	202	294	371
,,	..	*P. radiata*	207	411	376	192	377	325	143	313	287
,,	..	Rimu	187	368	443	165	342	419	111	265	363

Discussion of Table I

Table I indicates that kerosene, kerosene-turpentine, paradichlorobenzene, and orthodichlorobenzene are unlikely to prove permanently toxic to *Anobium*. While they all prevented infestation during the first flight season after treatment, their resistance to attack became progressively weaker with each year of seasoning. Larvæ recovered were healthy, and frass pellets indicated that feeding had been extensive.

Figures for zinc chloride would again indicate that this material was becoming, with age, increasingly susceptible to attack by *Anobium*. However, none of the recovered larvæ appeared to be normal, and dust in tunnels showed that much of the wood had been

chewed off but not passed into the gut. This preservative had no significant deterrent effect in preventing egg-laying.

Tanalith and Celcure samples were subjected to infestation only during the past flight season and it is too early to say what results will be, though dust shows that there is feeding in each case. There was no significant deterrent effect so far as oviposition was concerned.

Pentachlorphenol, zinc naphthenate, and chlorinated naphthalene were all good over the short period of the tests, and comparison with kerosene, kerosene-turpentine, and the two dichlorobenzenes shows that these results, at least in the case of zinc naphthenate and pentachlorphenol, were not due to the solvents or carriers. A conspicuous feature in regard to these three preservatives is that adult beetles did not live longer than five days when caged with any of these materials, and in no case were any eggs laid.

Egg-laying Preference Tests with Anobium

Table II gives results of preference tests where water-soluble preservatives were placed with untreated control blocks in the same cages. Oil-soluble preservatives are not included in the table, since no eggs were laid either on treated or untreated blocks when this type of preservative was placed in cages. Again adults died in a very short time.

TABLE II

Cage No.	Number of Female Beetles.	Preservative.	Date treated.	Timber	Number of Eggs laid.			Number of Larvæ tunnelling in			Number of Larvæ alive in		
											December,		Feb.,
					1943–44.	1944–45.	1945–46.	1943–44.	1944–45.	1945–46.	1944.	1945.	1946.
1	10	Tanalith ..	7/2/45	*P. radiata*	..		37	..		31	.		22
		Celcure .	?/4/40	,,	.		31	..	.	27	..	.	25
		Zinc chloride	11/6/44	,,	..	53	45	..	42	41	..	22	21
		,,	,,	Rimu	.	51	39	..	39	37	.	10	23
		,,	17/5/43	Kahikatea	161	78	33	143	66	30	42	20	26
		Control ..	11/5/43	,,	214	93	43	193	85	38	114	81	35
		,, ..	11/6/44	*P. radiata*	..	64	54	..	62	54	.	57	50
2	10	Tanalith ..	7/2/45	*P. radiata*	..	.	47	.	.	43	..	.	39
		Celcure ..	?/4/40	,,	..	.	53	.	.	47	..	.	42
		Zinc chloride	11/6/44	,,	..	66	38	..	61	35	..	14	27
		,,	,,	Rimu ..	..	43	21	..	31	17	.	22	9
		,,	17/5/43	Kahikatea	95	85	19	87	80	17	15	27	17
		Control .	11/5/43	,,	223	71	59	211	65	54	197	54	49
		,, ..	11/6/44	*P. radiata*	..	93	45	..	79	42	..	68	42
3	10	Tanalith .	7/2/45	*P. radiata*	..	..	31	..	..	27	..	..	21
		Celcure .	?/4/40	,,	..	..	42	..	..	37	..		29
		Zinc chloride	11/6/44	,,	..	42	47	.	38	42	..	20	27
		,,	,,	Rimu ..	..	47	23	..	41	19	..	25	11
		,,	17/5/43	Kahikatea	101	86	35	93	83	27	31	21	23
		Control ..	11/5/43	,,	294	86	40	265	74	36	243	69	31
		,,	11/6/44	*P. radiata*	..	57	49	..	55	43	..	35	34

Discussion of Table II

Table II indicates again that none of the water-soluble preservatives exercised any appreciable repellent effect as regards egg-laying, and there was a fairly high number of survivals in the zinc chloride samples, though all were better than the controls. Tanalith and Celcure have not been under test for more than three months, so are not directly comparable with the zinc chloride samples except as regards oviposition figures, and these are approximately the same.

Transfer of Anobium Larvæ to Treated Blocks

Table III gives results of experiments in which *Anobium* larvæ were transferred from untreated wood to holes drilled in treated blocks. Each experiment was carried on for eight months, after which blocks were split up and numbers of dead and live larvæ recorded. A further series of blocks that had been treated at the same time as the first lot was then set up.

TABLE III

Preservative.	Date Blocks treated	Timber.	Number of Replicates each Eight Months.	Number of Larvæ in each Experiment	Total number of Larvæ alive after seasoning for (in Months)				Percentage of Larvæ dead after seasoning of Blocks for (in Months)			
					8.	16.	24.	32.	8.	16.	24.	32.
Tanalith	7/2/45	*P. radiata*	5	30	0				100	.	.	
Celcure	?/4/40	,,	5	30	7				76·7	.	.	
Zinc chloride	17/5/43	,,	5	30	9	11	7	19	70·0	63·3	76·7	36·7
Pentachlorphenol K. 1	29/6/44	,,	5	30	0	0			100	100		.
Pentachlorphenol K. 2	,,	,,	5	30	0	0			100	100		
Pentachlorphenol K. 3	,,	,,	5	30	0	0			100	100		
Kerosene	11/5/43	,,	5	30	0	0	3	21	100	100	90·0	30·0
Kerosene and turpentine	,,	,,	5	30	0	1	7	23	100	96·7	76·7	23·4
Paradichlorobenzene	,,	,,	5	30	0	5	14	22	100	83·4	53·4	26·7
Orthodichlorobenzene	,,	,,	5	30	0	4	19	21	100	86·7	36·7	30·0
Timber Treatments	16/11/42	,,	5	30	0	0	0	0	100	100	100	100
Rentokil	24/4/45	,,	5	30	0	0*			100	100*		.
Control			5	30	27	26†	28†	27†	10	13·3	6·6	10

* Examination of the second Rentokil experiment showed that all larvæ were dead after two and a half months.

† Two adults emerged from control blocks before the termination of the sixteen-month tests, seven adults emerged from control blocks before the termination of the twenty-four-month tests, five adults emerged from control blocks before the termination of the thirty-two-month tests. For convenience, these adults have been recorded as surviving larvæ.

Discussion of Table III

The only water-soluble preservative that has been tested for longer than eight months is zinc chloride, so no comparison can be made between the three tested except for the first eight-months' test.

The mortality figures for zinc chloride were irregular and sometimes very low, but they do not give a true picture of the effect on larvæ. None of the surviving larvæ appeared to be in a healthy condition, and none had transformed to the pupal state, although all larvæ used in tests were second-year or older larvæ. Dust showed that a great deal of the wood had not been eaten.

Figures for kerosene, kerosene-turpentine, and the two dichlorobenzenes again showed that, though they were all excellent for killing larvæ, they did not exercise even a reasonably permanent control, and became progressively less effective as the treated blocks seasoned.

Of the permanent-type preservatives, zinc naphthenate (Timber Treatments) showed 100 per cent. control in the four tests covering a seasoning period of thirty-two months, while pentachlorphenol and Rentokil gave 100 per cent. control for sixteen and ten and a half months respectively.

Brush Treatments on Anobium-infested Timber

Table IV gives results of brush treatments on *Anobium*-infested sapwood matai using oil-soluble preservatives. All timber except the Boracure sample was taken from the same building and consisted of floorboards 4 in. × 1 in. Care was taken to select pieces as uniformly infested as possible, based on the numbers and freshness of exit holes. Untreated controls were cut from the same boards, except for the Boracure control, which consisted of a piece of the treated sample examined seven days after treatment. Samples were all split up forty-nine days after treatment.

TABLE IV

Preservative.	Number of Coats.	Wood Surface treated.	Larvæ recovered.						Total Percentage dead.
			First Series		Second Series		Third Series.		
			Alive.	Dead.	Alive.	Dead.	Alive.	Dead.	
Pentachlorphenol K. 1	1	Vertical	71	27	31	19	131	35	25·79
	2	,,	43	37	45	37	69	61	46·23
	3	,,	17	58	11	42	14	47	77·77
	4	,,	3	93	0	53	2	146	98·31
	1	Lower	89	23	27	8	134	42	22·60
	2	,,	46	39	19	12	142	97	41·69
	3	,,	29	53	21	41	32	124	72·66
	4	,,	2	77	1	39	9	88	94·44
	1	Top	42	20	27	14	94	40	31·22
	2	,,	39	42	29	29	101	86	48·15
	3	,,	5	57	0	23	23	127	88·08
	4	,,	0	45	2	47	1	143	98·73
Pentachlorphenol K. 2	1	Vertical	84	23	37	14	139	42	23·30
	2	,,	45	32	31	35	87	63	44·36
	3	,,	31	55	15	37	20	103	74·71
	4	,,	1	55	4	32	15	127	91·45
	1	Lower	53	13	35	9	153	63	26·10
	2	,,	37	46	49	38	127	79	43·35
	3	,,	14	32	25	37	31	135	74·45
	4	,,	0	42	7	37	5	141	94·82
	1	Top	58	19	15	3	87	19	20·39
	2	,,	12	39	33	28	93	73	50·36
	3	,,	14	25	0	26	30	123	79·81
	4	,,	0	76	6	44	0	127	97·62
Rentokil	1	Vertical	75	44	29	21	93	55	37·85
	2	,,	49	55	38	61	111	82	50·00
	3	,,	9	47	7	53	4	155	92·72
	4	,,	0	62	4	85	0	143	98·63
	1	Lower	73	26	47	33	127	68	33·95
	2	,,	24	39	46	58	104	103	53·47
	3	,,	0	33	3	52	8	99	94·35
	4	,,	0	104	5	63	11	158	95·30
	1	Top	42	39	29	77	49	67	60·39
	2	,,	10	79	13	83	6	136	91·13
	3	,,	0	32	2	49	3	133	97·60
	4	,,	0	85	0	68	0	169	100·00
Timber Treatments ..	1	Vertical	47	17	49	25	110	27	25·09
	2	,,	31	17	31	13	137	85	36·62
	3	,,	12	31	8	30	66	71	60·55
	4	,,	5	38	1	19	9	97	91·12
	1	Lower	64	8	36	31	105	28	24·63
	2	,,	33	29	43	36	135	50	35·27
	3	,,	9	23	14	36	63	121	67·66
	4	,,	4	44	2	47	7	104	93·75
	1	Top	57	26	21	6	83	31	28·12
	2	,,	19	13	23	29	125	79	42·01
	3	,,	17	42	21	49	26	125	77·12
	4	,,	0	34	6	36	10	107	91·70

TABLE IV—*continued*

Preservative.	Number of Coats.	Wood Surface treated.	Larvæ recovered.						Total Percentage dead.
			First Series		Second Series		Third Series		
			Alive.	Dead.	Alive.	Dead.	Alive.	Dead.	
Kerosene	1	Vertical	28	15	37	12	109	19	20·90
	2	,,	23	21	29	23	127	54	35·37
	3	,,	10	35	12	32	37	83	71·77
	4	,,	0	27	6	31	17	124	88·78
Paradichlorobenzene ..	1	Vertical	75	11	55	27	166	38	20·43
	2	,,	44	32	21	18	138	51	33·22
	3	,,	15	53	0	13	37	95	75·58
	4	,,	17	49	0	39	9	100	87·85
Boracure	?	?	2	56	..	..	..	..	96·55
Control	..	..	54	5	..	..	..	..	8·47
Control	..	..	59	4	20	0	99	12	8·24
	..	..	67	6	15	2	174	7	5·53
	..	..	123	2	29	3	138	8	6·40
	..	..	39	3	40	5	111	3	5·47
	..	..	49	8	37	2	165	11	7·72
	..	..	59	5	43	4	109	6	6·63

Discussion of Table IV

The figures show that, though top-surface applications of preservatives gave consistently better results, the differences between the three surfaces were not of any great extent.

In regard to the effect of the numbers of coats, it is apparent that none of the tested preservatives, with the exception, perhaps, of the chlorinated naphthalene (Rentokil), should be used in quantities of less than three flood coats per inch of timber thickness for sapwood matai or species of equal penetrability.

While kerosene and paradichlorobenzene gave fairly high degrees of control, Tables I and III showed that they were unlikely to afford even a reasonable period of protection.

In general, it appears that chlorinated naphthalene, pentachlorphenol, and zinc naphthenate are all good preservatives for treatment of infested sapwood matai.

The surviving larvæ were all found just beneath the surface on the sides opposite to those treated. In vertical treatments, nearly all larvæ were found in the top third of the boards.

To obtain a clearer idea as to the relative merits of the preservatives under test, the following is a list giving the average percentage mortalities caused by the third and fourth coatings for the three surfaces :—

	Per Cent.
Chlorinated naphthalene	96·43
Pentachlorphenol K. 1	88·33
Pentachlorphenol K. 2	85·47
Zinc naphthenate	80·31

Coat-for-coat comparisons show that :—

Four coats of chlorinated naphthalene or pentachlorphenol K. 1 were better than any others.

Three coats of chlorinated naphthalene were better than four coats of pentachlorphenol K. 2 and zinc naphthenate.

Two coats of chlorinated naphthalene were almost equal to three coats of zinc naphthenate.

One coat of chlorinated naphthalene was almost equal to two coats of pentachlorphenols K. 1 and K. 2 and better than two coats of zinc naphthenate.

The pentachlorphenols were approximately equal coat for coat and better than zinc naphthenate, except for single coats of the latter, which were better than pentachlorphenol K. 2.

Brush Treatments of Calotermes-infested Timber

Table V gives the results of brush treatments of 6 in. × 1 in. kahikatea infested by *Calotermes brouni* and using the same technique as for Table IV tests, except that only the top surface was treated and samples were examined twenty-one days after treatment.

TABLE V

Preservative.	Number of Coats.	Termites recovered.						Total Percentage dead.
		First Series.		Second Series.		Third Series.		
		Alive	Dead.	Alive.	Dead.	Alive	Dead	
Pentachlorphenol ..	1	23	305	0	147	99	267	85·40
	2	11	4	14	441	39	131	90·00
	3	0	117	0	33	0	246	100·00
	4	0	247	0	75	0	177	100·00
Rentokil	1	36	469	12	281	0	324	95·72
	2	0	65	0	15	0	111	100·00
	3	2	105	0	166	5	33	97·74
	4	0	49	0	58	0	227	100·00
Timber Treatments	1	48	534	19	306	74	40	86·19
	2	0	61	0	5	48	363	89·93
	3	0	111	0	106	0	9	100·00
	4	0	50	0	243	0	32	100·00
Controls	..	340	11	193	9	38	0	3·38

Discussion of Table V

Table V shows that all three preservatives are satisfactory for use against this termite. A point that is of importance, however, is that even three coats may not kill all termites if their galleries are narrow and on the side opposite to that treated; this occurred with the chlorinated naphthalene. On the other hand, if galleries are numerous and approach both surfaces, a single application of any of these preservatives may be effective, since the surviving termites in all cases of treated wood were in a shrivelled condition and probably would not have lived much longer.

GENERAL DISCUSSION AND RECOMMENDATIONS

Consideration of results given by these preliminary tests indicate that such preparations as kerosene, kerosene-turpentine, paradichlorobenzene, and orthodichlorobenzene, while giving good control of insects already present in timber, are unlikely to prevent future infestation of the treated wood. For this reason alone it is strongly recommended that their use be discontinued. In addition, the cost of the more permanent types of preservatives is very little more than for the former types, and the trouble involved in their application is the same in both cases.

Of the water-soluble preservatives, zinc chloride is the only one on which oviposition tests have been carried out for longer than three months, and while the numbers of surviving larvæ were often high, the actual condition of these larvæ indicated that zinc-chloride-treated wood was unpalatable to them. The same remarks apply to Tanalith and Celcure in egg-laying tests. None of the water-soluble preservatives acted as repellents during oviposition by *Anobium* beetles.

All the oil-soluble preservatives prevented oviposition by *Anobium* adults, and also were toxic to the beetles.

In considering results of tests where *Anobium* larvæ were transferred to treated blocks, it is apparent that, though the three water-soluble preservatives made the wood more or less unpalatable to *Anobium* larvæ, there was not sufficient toxic material in the amount of wood ingested to cause death in many cases. All three prevented transformation of larvæ to adults or pupæ, but though the diameters of tunnels in treated wood were on an average less than those in control blocks, the lengths of tunnels were approximately the same. This point is an important one and warrants further attention. It is recommended that the amount of toxic components in these preservatives be increased where feasible. This may not be possible to any marked extent with zinc chloride, due to the effect heavy concentrations have in causing collapse of cell structures in wood.

All the oil-soluble preservatives gave 100 per cent. control of transferred larvæ, and though the samples were examined at eight-month intervals, these preservatives caused death of larvæ in less than two months.

Results of brush treatments with the three oil-soluble preservatives are all satisfactory for both *Anobium* and *Calotermes brouni*. In general, it is recommended that one liberal brush coating should be applied for each ¼ in. in thickness of sapwood timber. In commercial practice surface spraying has superseded brush applications, but it is unlikely that there would be a great deal of difference between the two methods so far as penetration and amounts of treating fluid are concerned. The advantage of spraying is that it is much quicker. In commercial practice, too, the conditions for treating would not be as favourable as those for these small tests, due to interference by studs, weatherboards, lining, wallpapers, and height above ground-level.

An important factor in recording results with preservatives against *Anobium* is that larvæ are able to tunnel in wood treated with oil-soluble preservatives for almost three weeks. This applies only when there is no free liquid in cell cavities or on wood fibres. The writer has found live larvæ in timber which chemical tests showed to be completely penetrated by preservative ; and in the case of the sample in Table IV treated by Boracure Ltd. with their standard flood-spray technique, the " control " sample consisted of a piece of treated wood examined seven days after treatment, when fifty-four larvæ were still alive and five dead. Examination of *Anobium* tunnels showed that dust made prior to treatment consisted almost entirely of frass pellets, whereas that made after treatment was composed mainly of " chewings " with practically no frass, showing that the wood had been chewed off but not passed into the gut.

In subsidiary experiments, to find out how long they could live without food, second- and third-year *Anobium* larvæ were kept at room temperatures in ointment-jars containing damp, crumpled cellophane disks. These larvæ were examined each week and more water added if necessary. At the end of four weeks, nineteen of the fifty larvæ were still alive ; on the thirty-fifth day, only five were alive, and these were dead by the thirty-seventh day. Examination of cellophane disks showed that larvæ had chewed holes through them in some cases, but that there were no frass pellets such as occurs when feeding takes place. It thus appears that, in the absence of desiccating factors, *Anobium* larvæ can survive long periods without food.

This fact is important in interpreting effects of timber-preservatives, since the full value of those that are not actually contact insecticides will become apparent only when larvæ are compelled by starvation to eat treated wood. As shown above, this may not take place for three or more weeks after treatment.

In all the above experiments no samples were retained for longer than one year, so it is not known whether or not the surviving larvæ recorded in the tables would have succumbed to longer exposures to the treated timbers.

ACKNOWLEDGMENTS

The writer is greatly indebted to the manufacturers of Rentokil Timber Fluids for the samples of chlorinated naphthalene; to Messrs. Boracure Ltd. (N.Z.) for supplies of pentachlorphenol and the other constituents of their preservatives; and to Messrs. Timber Treatments, Ltd., for supplies of zinc naphthenate solutions. Thanks are due, too, to New Zealand Forest Products, Ltd., for supplying the Wolmanized and Celcurized *Pinus radiata* samples, and to authors of numerous papers from which notes were made before this paper could be completed.

APPENDIX

Krogh and Tooke (1944) give the following formulæ for pentachlorphenol solutions :—

		Per Cent. by Weight.
(1)	Pentachlorphenol	3·85
	Linseed-oil	21·15
	Mineral turpentine	75·00
(2)	Pentachlorphenol	4·00
	Seal-oil	20·00
	Mineral turpentine	76·00
(3)	Pentachlorphenol	4·00
	Dehydrated castor-oil	16·00
	Mineral turpentine	80·00

These authors state that the solubility by weight of pentachlorphenol at room temperatures is 15 per cent. in linseed-oil, 20 per cent. in seal-oil, and 42 per cent. in dehydrated castor oil (Sostrol).

They also state that for *Pinus radiata* and five other species of *Pinus* a one-minute dip gives adequate protection. In South Africa the cost of these treatments to give a dry-salt retention of 0·13 lb. per cubic foot is 1s. 6d., 1s. 1½d., and 1s. 4d. per cubic foot according to whether linseed, seal, or castor oils are used. The cost in New Zealand would be higher, as shown by the comparative costs listed below :—

——	South Africa.	New Zealand.
	s. d.	s. d.
Mineral turpentine (per gallon)	2 9	3 8
Linseed-oil (per gallon)	10 0	18 9
Pentachlorphenol (per pound)	2 0	2 6

This cost can be reduced by using either lighting or power kerosenes at a cost per gallon in New Zealand of 2s. 2d. and 1s. 11d. respectively in place of the turpentine, as the kerosene penetrates as readily.

Chlorinated naphthalene has given excellent results in the international termite exposure tests in Australia, America, South Africa, and Honolulu. In all of these countries they have been tested for over fourteen years, and the only preservative giving better records is creosote, which cannot be used where staining is of importance or where timber is to be painted.

Zinc naphthenate is a comparatively recent addition to the timber-preservatives, and no service records are available to the writer, though they probably exist.

Pentachlorphenol service records are scattered and lack detailed information, but in America (1944) records show that 198 posts treated with pentachlorphenol in spent crank-case oil were still in service after seven years. The same report gives another batch of samples as undamaged after five years in highway service. Further pentachlorphenol tests were started in 1938 and 1939, all samples being in good condition in 1943. Untreated controls were destroyed in fifteen months.

The organic oils in the formulæ are to increase solvency and prevent "blooming" of crystals of pentachlorphenol on the wood surface as the carrier oils dry out. It is these organic oils that give most of the odour to pentachlorphenol solutions, though the carrier oils also possess characteristic odours. Pentachlorphenol itself is almost odourless. Other agents to prevent "blooming" are copal ester gum or turpin resin, but any organic oils would serve the same purpose to varying degrees.

Zinc naphthenate has a very strong smell which is offensive to some people and causes headaches. Theoretically this odour means that the chemical is volatile, so it will be of interest to see whether loss of its characteristic smell is correlated with susceptibility to borer attack of timbers treated with it.

Chlorinated naphthalene has a slight odour that might prove unpleasant to some people.

The water-soluble preservatives, Tanalith, Celcure, and zinc chloride, have been tested overseas against termites and decay, but service records for severe outside conditions are very variable from one country to the next. For example, for approximately the same dry-salt retention of 0·7 lb. per cubic foot of wood the Tanalith average life varies from 37 months in the Panama Canal zone to 128 months in Australia.

Zinc chloride has an average life for timber, treated to a retention of 1·5 lb. dry salt per cubic foot, of 12 months in South Africa and a maximum of 80 months for the same retention figures in Australia. Untreated controls had an average life range of from 8 months in America to 28 months in Australia.

However, in New Zealand buildings the water-soluble preservatives will not be exposed to severe leaching conditions or to such severe insect infestations, and service life should be correspondingly greater.

REFERENCES

KELSEY, J. M.; SPILLER, D.; and DENNE, R. W. (1945): Biology of *A. punctatum*. *N.Z. J. Sci. & Tech., 27 (Sec. B)*, 60.

KROUGH, P. M. D., and TOOKE, F. G. C. (1944): The Toxicity and Penetrative Capacity of certain Pentachlorphenol Wood-preservative Solutions. *J. S. African Forestry Assoc., No. 12*, 53–8.

HATFIELD, I. (1944): Information on Pentachlorphenol as a Wood-preserving Chemical. *Am. Wood Pres. Assoc., 40.* (Reprint pp. 1–19).

HUNT, G. M. and SNYDER, T. E. (1944): "An International Termite Exposure Test." 15th Progress Report.

A VARIATION OF THE TERMITE *COPTOTERMES LACTEUS* FROGG. FROM NEW ZEALAND

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Summary

A distinct variation of the termite *Coptotermes lacteus* is described from material collected in Auckland during 1941–43. Though it has not been recorded from Australia, it is considered to be native to that country and has been accidentally introduced into New Zealand in power poles or sleepers. Until more is known as to the range of variation of micraster shapes for a species it is not intended to erect a new species or variety.

INTRODUCTION

THE following descriptions apply to two soldiers and one nymph collected on 18th June, 1941, by Mr. D. Bambury, and to six alates, numerous soldiers, and nymphs collected on 8th March, 1943, by Mr. G. V. Cronin. The first sample was recorded from a tramway power-pole and the second from *Pinus radiata* D. Don stumps in a City Council reserve, Point Chevalier Road. These stumps were close to the power-pole, but until the stumps and pole are removed it will not be possible to say whether the infestation started in the pole, stumps, or tramway sleepers beneath the sealed road surface.

After superficial examination the termites were identified by the writer as a small variety of *Coptotermes lacteus* Frogg., but when permanent slide mounts were made of the wings it became apparent that the spines on wing membranes were longer than for typical *C. lacteus*, and, more importantly, the micrasters were conspicuously stellate (Fig. 1C), whereas those of typical *C. lacteus* were thornlike (Fig. 1D), (1944). Coloration, too, was different, being dark to light brown for alates of the variant and dark brown to black for typical *C. lacteus* alates. Soldiers of the latter had heads shading from yellow to brown, with brown gular areas, whereas those of the variant were a uniform yellow in each area.

A representative sample of all castes was sent to Australia for identification, and Mr. Gay, of Canberra, found that, though general appearance of alates and the measurements of soldiers made them appear to be a small variety of *C. lacteus*, there was no doubt that the spines and micrasters on wings of the Auckland series were quite different from those of typical *C. lacteus*, and, indeed, did not appear to fit in with the wing ornamentation of this species throughout any part of its range (1942). However, Mr. Gay considers it unlikely that the Auckland material represents anything more than a varietal difference at the most.

Later, on re-examination of *C. lacteus* material supplied by Mr. G. F. Hill from Coree Creek, A.C.T., 1938, the writer found that there were two detached wings with stellate micrasters. However, Mr. Hill does not list the range of variation in shape of micrasters for a species (1942), and since the alates present in the sample all possessed their full complements of wings it is just possible that, by mistake, wings from another colony may have been included in the named material.

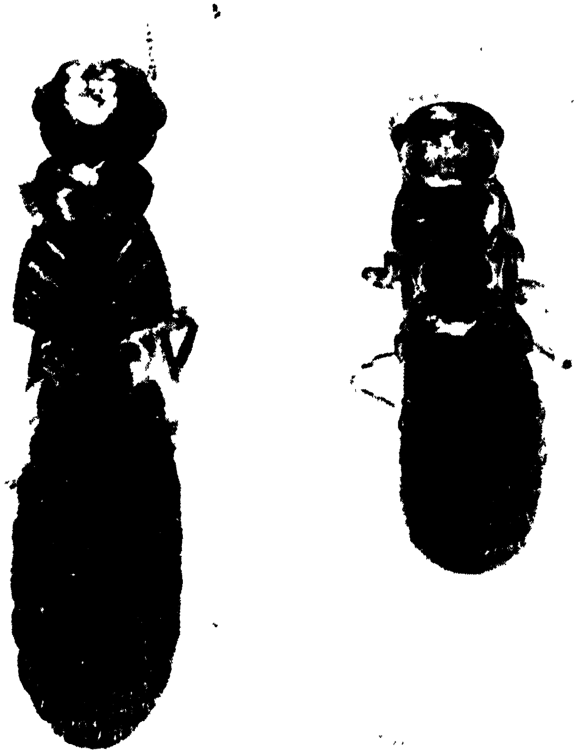


FIG. 1A.—Alate (wings removed) of *C. lacteus* on left and of the variation on the right.

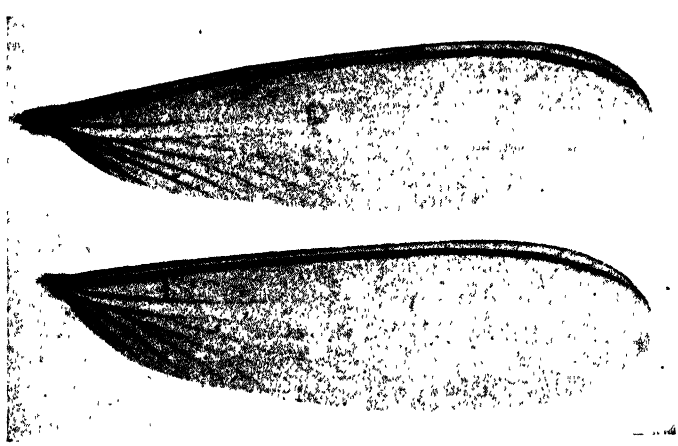


FIG. 1B.—Wings of the variation (spots are dust particles caught beneath wing spines).

In spite of the fact that no termite with similar alate characteristics has been recorded from Australia it is considered, in view of the Coree Creek material, to be an Australian species accidentally introduced in power or transport poles, sleepers, &c. No species of genus *Coptotermes* has been found native to New Zealand, and the colony in the stumps was so large that, if it is typical for this termite, it is unlikely that the species would have been overlooked for such a long time.

FIG. 1C.—Wing micrasters of *C. lacteus*.

Though it is not intended to give specific or varietal importance to this termite—at any rate until more is known about the degree of variation in shape of wing micrasters likely to occur in a given species recognition must be given to the fact that the body-colour differences between alates of the variety and typical *C. lacteus* are as conspicuous as are those between *C. acinaciformis* and *C. raffrayi*.

When sizes of wings and shapes of micrasters are considered, the differences between *C. lacteus* and the Auckland series are very much more clearly defined than are the same characters for *C. acinaciformis* and *C. raffrayi*.

FIG. 1D.—Wing micrasters of variation.

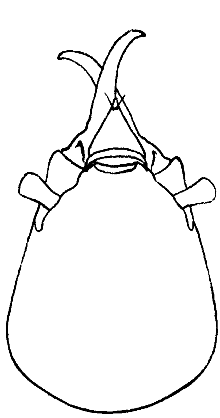


FIG. 2A.—Soldier head of the variation.

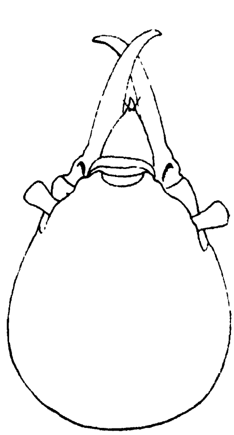


FIG. 2B.—Soldier head of *C. lacteus*.

The colour differences between soldier heads of *C. lacteus* and the variety are more marked than are those between *C. acinaciformis* and *C. raffrayi*, while the range in size of soldiers of the last two species is no more distinct than are those of *C. lacteus* and its variation. In the absence of alates, however, the writer thinks it would not always be possible to definitely separate typical *C. lacteus* and the Auckland series on soldier characteristics in those instances where newly transformed soldiers are present.

In the event of the Auckland material proving to be a true species the characteristic shape of the wing micrasters—the most conspicuous feature of this termite—would indicate the specific name *stellatus* if it is not already preoccupied.

As a matter of interest it may be mentioned that our native dampwood termite *Stolotermes ruficeps* Brauer, has similar stellate micrasters on wing membranes.

DESCRIPTION OF CASTES

(Measurements are in units (32·5 = 1 mm.) and in brackets in millimetres)

Alate (Fig. 1A)

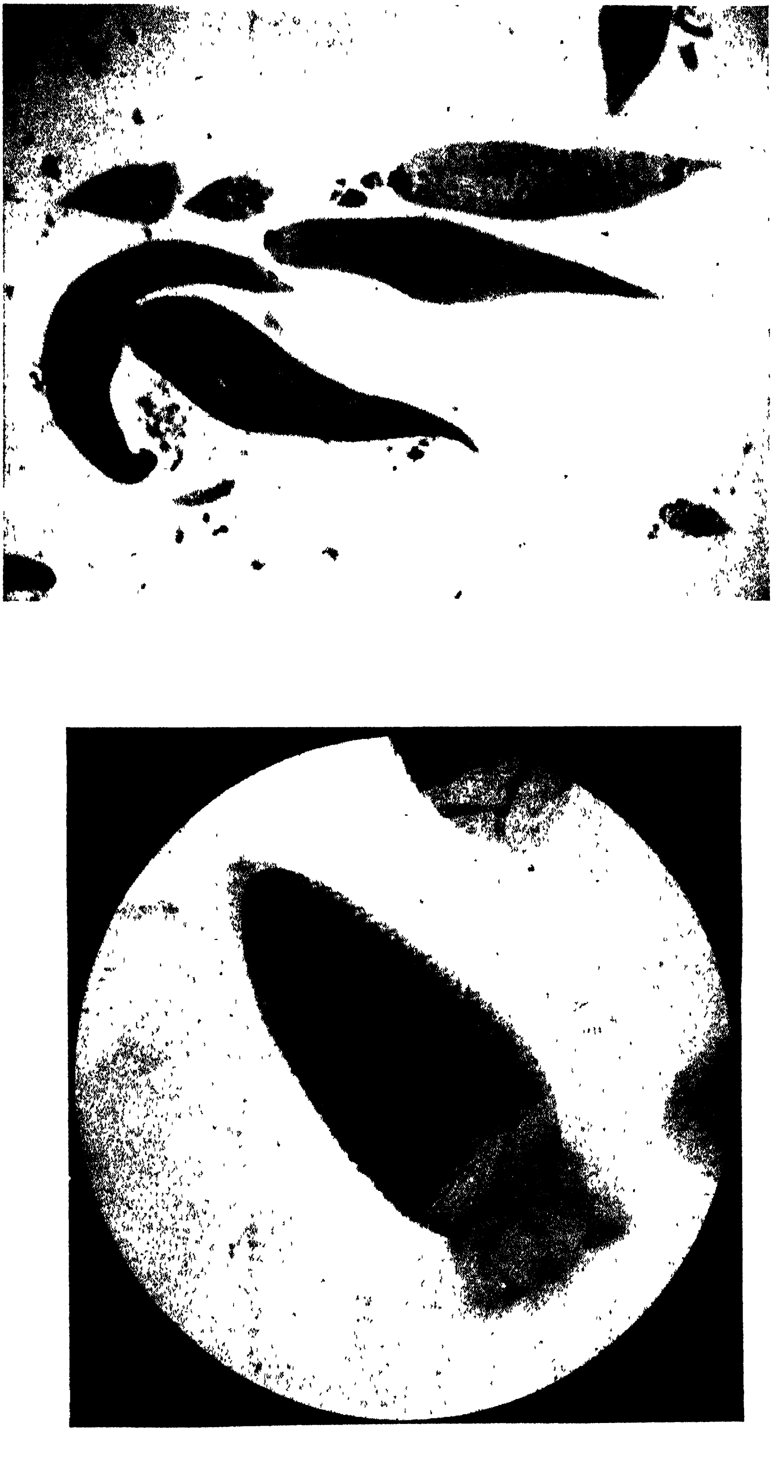
Colour.—Head, thorax, and abdomen a uniform brown on top; sternites darker brown at sides, light brown in centre; clypeus and ocelli white; wings smoky grey to brown.

Size.—431 units (13·26 mm.) long with wings; 194 units (5·96 mm.) without wings; forewings with stumps, 360 units (11·07 mm.) long; without stumps, 331 units (10·18 mm.) long.

Head.—50 × 39 units (1·53 × 1·2 mm.) across eyes; oval in outline; labrum tongue-shaped; clypeus pale cream and membraneous; eyes large; ocelli large and reniform from above; fenestræ transversely oval and pale brown; spine insertions appear as numerous white dots on the head surface; antennæ 75 units (2·3 mm.) long, of 16 joints; first joint long and broad, second one-third as long as first and three-quarters its width, third half as long as second and narrower, remaining segments progressively longer, terminal one oval; all joints heavily spinose.

Pronotum.—21 × 32 units (0·64 × 0·98 mm.); bowl-shaped and spinose.

Wings (Fig. 1B).—Smoky grey to brown; much shorter than for typical *C. lacteus*, membrane thickly beset with spines and stellate micrasters (Fig. 1C); spines longer than for typical *C. lacteus*, which has thornlike micrasters (Fig. 1D). *Fore Wing:* The first vein runs close and parallel to the costal margin, which it joins at the distal end of the wing; it may or may not be joined to the costal margin by a very short diagonal vein about mid-length of the wing. The second vein arises from the first just before the wing suture and passes back through the anterior one-third of the width of the wing to branch once more near the distal quarter of its length, and may or may not send one or more short diagonals up to join the vein above. The third vein runs out through the approximate centre of the wing to branch several times, all branches joining the posterior margin of the wing. *Hind Wing:* The first vein runs close and parallel to the costal margin to which it is attached at the outer extremity of the wing. The second arises from the first just posterior to the suture to run out through the anterior third of the wing, branching once or more distally before joining the wing margin. The third passes out through the approximate centre of the wing to give off numerous branches to the posterior margin. All margins of wings have spines projecting to a greater extent than for typical *C. lacteus*. *Mandibles, maxillæ,* legs, &c., similar to those of other *Coptotermes* species (1944).



[Photo by R. J. Blick.

FIG. 3 A and B.—Two types of protozoa from the hind intestine of the variation.

Soldier

Colour.—Head a uniform yellow, unlike that of typical *C. lacteus*, which is brownish round the anterior half.

Size.—183 × 40 units (5·63 × 1·23 mm.); head, 75 × 40 units (2·3 × 1·23 mm.) to mandible tips.

Head (Fig. 2A).—The widest part of head is two-thirds more back from the front of the head (excluding mandibles), whereas in typical *C. lacteus* (Fig. 2B) the widest part is less than two-thirds back from the front of the head. For two-thirds of the head length the sides are almost straight, whereas in *C. lacteus* they are strongly convex throughout.

Eyes, fenestræ, and ocelli absent; fontanelle large and conspicuous; antennæ of about 14 segments and 47 units (1·44 mm.) long, with sizes of joints similar to alate.

Pronotum.—18 × 30 units (0·55 × 0·92 mm.); bowl-shaped and heavily spinose

Mandibles, maxillæ, legs, &c., as for other *Coptotermes* species, except that maxillæ are paler in colour than for typical *C. lacteus*.

In actual size there is nothing to separate the Auckland series from *C. lacteus* on soldier characteristics, and measurement ranges for soldier heads are the same for both termites. It is the paler coloration, the almost straight-sided, turbinate head, and the location of the widest part of the head in relation to head-length that will be found most convenient for separating the Auckland material from *C. lacteus* on soldier characteristics. On alate characters the paler coloration of the body, the smaller wings, and the stellate micrasters will clearly separate the variant from typical *C. lacteus*.

ACKNOWLEDGMENT

The writer is indebted to authorities in Canberra, Australia, for the trouble they have always taken in examination of material from New Zealand, and for suggestions and named specimens; also to Mr. R. J. Blick, of the Cawthron Institute, for the excellent photographs.

REFERENCES

HILL, G. F. (1942): "Termites (Isoptera) from the Australian Region," pp. 156–62.

KELSEY, J. M. (1944): The Identification of Termites in New Zealand. *J. Sci. & Tech. 25 (Sec. B)*, pp. 245–7.

SOME MINOR CONSTITUENTS OF PIG BACK FAT

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Summary

A large sample (4 kg.) of the back fat from pigs fattened on buttermilk has been examined. Capric acid (0·2 per cent.) and lauric acid (0·2 per cent.) have been identified as minor components. A trace of decenoic acid is probably present, but the nature of the unsaturated acid accompanying the C_{12} fraction is obscure. Saturated acids of molecular weight greater than that of stearic acid are present to the extent of 0·1 per cent.; at least half of this material is behenic acid or higher molecular weight homologues. The unsaponifiable matter (0·19 per cent.) contain cholesterol (0·07 per cent.), a mixture of saturated hydrocarbons approximating in composition to hexacosane (0·02 per cent.), various pigments, and unidentified components.

INTRODUCTION

IN the course of an investigation relating the chemical composition of pig depot fat to its growth rate(1), evidence was obtained that the C_{20} unsaturated acids had hitherto been incompletely characterized. From 4 kg. of pig depot fat, Δ 11–12 eicosenoic acid was subsequently isolated(2), and evidence was obtained for the presence of other C_{20} polyethenoid acids, including eicosadienoic acid. The present paper describes other minor constituents examined incidentally in the course of the latter investigation.

EXPERIMENTAL

Bulked inner and outer back fat (4,019 g.) from pigs fed only buttermilk during the fattening period was extracted as previously described(3). The fat was hydrolyzed with alcoholic KOH, and the unsaponifiable matter (7·6 g.) was removed from the resulting soaps by continuous extraction with ether. The recovered fatty acids (3,664 g.) were converted into ethyl esters (3,908 g.). These were fractionated under vacuum of a Hyvac pump using a 5-litre flask, an electrically heated column 112 cm. high, 20 mm. in diameter, packed with 10 mm. sections of 6 mm. glass tubing, and a stillhead designed for total reflux and variable take off. Table 1 gives the result of this fractionation.

TABLE I.—FRACTIONAL DISTILLATION OF ETHYL ESTERS OF PIG BACK FAT

Fraction.	Weight (*g*.).	b.p. (°C.) (*ca*. 0·1 mm.).	Sap. Equiv.	Iod. Val. (Wijs 1 Hour).
F_1	214	142	275·7	25·4
F_2	1,130	142	291·6	37·3
F_3	1,480	142–150	299·0	47·8
F_4	694	150–160	306·6	59·9
F_5	397	..	309·7	69·2
Total ..	3,915			

Table II gives the results of refractionation of 171 g. of fraction F_1 in an electrically heated column packed with glass helices.

TABLE II.—REFRACTIONATION OF FRACTION F_1

Fraction.	Weight (g.).	b.p. (°C.) (ca. 0·1 mm.).	Sap. Equiv.	Iod. Val. (Wijs 1 Hour)
F_{11}	1·29	120–130*	200·2	17·2
F_{12}	1·67	130*	198·4	14·5
F_{13}	1·90	50–75	200·8	12·3
F_{14}	2·15	75–80	211·1	8·9
F_{15}	1·94	80–85	218·4	7·0
F_{16}	2·60	85	219·0	5·4
F_{17}	1·60	85–93	219·3	7·7
F_{18}	2·85	93–98	237·0	7·6
F_{19}	2·22	98	244·7	8·2
F_{110}	5·36	98–104	254·6	6·1
F_{111}	12·33	104	256·1	6·9
F_{112}	136·00	..	289·6	30·3
Total ..	171·91			

* Vacuum of water pump.

The C_{10} Acids

The acids recovered from fractions F_{11}, F_{12}, and F_{13} (3·27 g.) were combined and crystallized from 60 ml. of acetone at −60°C. The precipitate (1·44 g.) had a melting-point 27–28°C., and mixed with genuine capric acid melted at 30–31°C. A p-toluidide was prepared from this fraction which, after recrystallization, melted at 74–74·5°C. and showed no depression of melting-point on admixture with genuine capric p-toluidide, melting-point 75·5–76°C.

The mother liquor from the above crystallization was cooled to *ca* −80°C. A further 1·39 g. of precipitate was removed by filtration. The soluble material (0·44 g.) had an iodine value of 57 and a neutralization equivalent of 173·0.

The C_{12} Acids

Methyl esters were prepared from the acids recovered from fractions F_{14}–F_{19}. These were fractionated, giving the results of Table III.

TABLE III.—FRACTIONATION OF METHYL ESTERS OF C_{12} ACIDS

Fraction.	Weight (g.).	b.p. (°C.) (ca. 0·1 mm.).	Sap. Equiv.	Iod. Val. (Wijs 1 Hour).
A_1	0·90	45–71	195·4	10·0
A_2	1·05	71	205·2	6·0
A_3	1·59	71	207·1	6·3
A_4	1·25	71–90	216·4	10·2
A_5	1·65	90	239·2	8·5
A_6	1·04	..	238·2	8·5
Total ..	7·48			

As no fraction corresponding to almost pure methyl laurate (sap. equiv. 214) was obtained, the acids recovered from fractions A_2 and A_3 (2·04 g.) were crystallized from acetone, as shown in Table IV.

TABLE IV.—CRYSTALLIZATION OF ACIDS FROM FRACTIONS A_2 AND A_3

2·04 g. (neut. equiv. 192·0 ; iod. val. 6·5)

Crystallized from 30 ml. of acetone at -5°c.

A_{231}: Insoluble (0·48 g.), m.p. 42–43°c. — Soluble (1·56 g.)

Crystallized from 30 ml. acetone at -30°c.

A_{232}: Insoluble (0·44 g.), m.p. 40·5–41°c. — Soluble (1·10 g.)

Crystallized from 30 ml. acetone at -50°c.

A_{233}: Insoluble (0·73 g.), m.p. 39·5–41·5°c. — Soluble (0·37 g.)

Crystallized from 30 ml. acetone at -80°c.

A_{234}: Insoluble (0·11 g.) — Soluble (0·26 g.)

Fractions A_{231}, A_{232}, and A_{233} gave no depression of melting-point on admixture with genuine lauric acid, melting-point 43°c. The combined neutralization equivalent of these fractions was 199·7 (theory for lauric acid, 200·0). A portion (0·06 g.) of the soluble fraction A_{235} was treated with 2, 4-dinitrophenylhydrazine dissolved in alcohol. A distinct intensification of colour was observed, but on evaporation to small bulk and cooling, only oily material separated.

The C_{20} "Solid" Acids

The acids recovered from fraction F_5 (Table I) were crystallized twice from acetone (4,000 ml.) at -10°c. The precipitate (110 g.) was methylated, giving 114 g. of methyl esters (S, sap. equiv. 295·9, iod. val. 28·2). Table V gives the result of fractionation of 111 g. of this material.

TABLE V.—FRACTIONATION OF METHYL ESTERS (S) OF "SOLID" ACIDS FROM F_5 (TABLE I)

Fraction.	Weight (g.).	b.p. (°c.) (ca. 0·1 mm.).	Sap. Equiv.	Iod. Val. (Wijs 1 Hour).
S_1	64·5	140	295·9	24·1
S_2	22·7	140	296·6	20·3
S_3	13·0	140–150	302·4	22·9
S_4	3·6	150	320·3	40·7
S_5	2·8	150–170	325·9	62·8
S_6	1·0	170	323·6	64·3
S_7	3·2	..	302·0	79·8

The acid recovered from fractions S_5 and S_6 (2·61 g.) were crystallized from acetone, as shown in Table VI.

TABLE VI.—CRYSTALLIZATION OF C_{20} ACIDS FROM FRACTIONS S_5 AND S_6

2·61 g. (neut. equiv. 310·0; iod. val. 61·0)

Crystallized from 30 ml. of acetone at 15°c.

S_{561}: Insoluble [0·84 g.]

Crystallized from 10 ml. methyl alcohol at 15°c.

S_{5611}: Insoluble [0·57 g.] (neut. equiv. 340·3)

S_{5612}: Soluble [0·27 g.] (neut. equiv. 315·4)

Soluble

Crystallized from 30 ml. acetone at -30°c.

S_{562}: Insoluble [0·39 g.] (iod. val 7·8; neut. equiv. 312·3)

Soluble crystallized from 30 ml. acetone at —40°c.

S_{563}: Insoluble [0·25 g.] (iod. val. 44·4; neut. equiv. 296·4)

Soluble crystallized from 30 ml. acetone at —80°c.

S_{564}: Insoluble [0·34 g.] (iod. val. 77·7; neut. equiv. 306·2)

S_{565}: Soluble [0·79 g.] (iod. val 157·2; neut. equiv. 297·0)

The high neutralization equivalent of fraction S_{5611} was confirmed after careful removal of any traces of unsaponifiable matter by extraction of the soaps with ether and recovery of the purified acids. Its melting-point (69–70°c.) was raised to 73·5–74°c. by recrystallization three times from acetone and once from a mixture of petroleum ether and benzene.

Fraction S_{564} (0·26 g., iod. val. 77·7) was oxidized by dilute alkaline permanganate, as described by Lapworth and Mottram(5). The product was mostly petrol-soluble and hence was reoxidized under substantially the same conditions, but the reaction mixture was left for a period of twelve hours. The resulting hydroxy-acids (0·121 g.) were recrystallized from ethyl acetate several times, finally melting at 124–125·5°c. Analysis gave C = 69·8, H = 11·3. Dihydroxy arachidic acid prepared from Δ 11-12 eicosenoic acid requires C = 69·8, H = 11·6, melting-point 131°c.(6).

The Unsaponifiable Matter

By crystallization of 3·81 g. of unsaponifiable matter from methyl alcohol, the following fractions were obtained :—

D_1 0·21 g. : Insoluble in methyl alcohol at 50°c.
D_2 1·15 g. : Soluble in methyl alcohol at 50°c., insoluble in methyl alcohol at —5°c.
D_3 2·45 g. : Soluble in methyl alcohol at —5°c.

(*a*) *The Sterol Fraction.*—Fraction D_2, being mainly sterol, was dissolved in petrol and chromatographed on a column of alumina* 25 cm. high and 12 mm. in diameter. Table VII gives the characteristics of successive fractions eluted from the column.

TABLE VII.—CHROMATOGRAPHIC ANALYSIS OF FRACTION D_2

Fraction.	Eluted with	Weight (*g.*)	m p.°c	Comments.
D_{21}	50 ml. pet ether..	0·18	Below 80	Waxy, added to D_1.
D_{22}	25 ml. ,, ..	0·01	,,	Rejected.
D_{23}	25 ml. ,, ..	0·02	,,	,,
D_{24}	25 ml. ,, ..	0·01	,,	,,
D_{25}	25 ml. acetone .	0·32	144–146	Recryst. from acetone, m.p. 148–9°c.
D_{26}	25 ml. ,, ..	0·33	143–145	Recryst. from acetone, m.p. 147–8°c.
D_{27}	25 ml. ,, ..	0·15	95–115	Recryst. from acetone, mp. 146–7°c.
D_{28}	25 ml. benzene + acetone (1 1)	0·13	130 136	Recryst. from acetone, m.p. 147–8°c.

Fraction D_{25} and D_{26} were almost pure cholesterol, giving, after recrystallization from acetone, no depression of melting-point on admixture with genuine cholesterol, melting-point 149°c. A trace of coloured material in fractions D_{27} and D_{28} was easily removed by recrystallization, giving a further 0·10 g. of cholesterol. Allowing for slight losses in crystallization, it is estimated that these four fractions contained a total of approximately 0·80 g. of cholesterol.

(*b*) *The Hydrocarbon Fraction.*—Fractions D_1 and D_{21} were chromatographed as described above and in Table VIII.

TABLE VIII.—CHROMATOGRAPHIC ANALYSIS OF FRACTION D_1 – D_{21}

Fraction.	Eluted with	Weight (*g.*).	Comments.
D_{11}	50 ml. petrol	0·24	See below.
D_{12}	50 ml. acetone	0·09	Sterol by digitonin, 0·02 g. Remainder orange in colour.
D_{13}	.	(0·06)	Adsorbed residue ; rejected.

Fraction D_{11} was crystallized from acetone. The resulting material soluble in hot acetone (0·10 g.), but insoluble in cold acetone (0·08 g.), had the following almost identical characteristics : m.p. 55–59°c. ; iod. val. 2·7 (Kaufmann ½ hour) ; C = 84·6, 84·7 ; H = 14·6, 14·6 ; mol. wt. (Rast) 370. Hexacosane ($C_{26}H_{54}$) requires m.p. 56·5°c. ; iod. val. 0·0 ; C = 85·3 ; H = 14·7 ; mol. wt. 366.

* Merck's " Nach Brockmann."

(c) *The Fraction Soluble in Cold Methyl Alcohol.*—Fraction D_3 (2·45 g.) was dissolved in boiling 90 per cent. ethyl alcohol. A solution of digitonin in boiling 95 per cent. ethyl alcohol was added in amount sufficient to precipitate all the sterol. The solution after standing overnight at room temperature was filtered. The alcohol solution was diluted with water and extracted several times with ether, the combined ether extracts being then thoroughly washed with water to remove excess of digitonin. After evaporation of the ether, the non-sterol portion (1·84 g.) was dissolved in 15 ml. of petroleum ether and cooled to —15°c. A small amount (0·13 g.) of precipitate (melting-point 61 63°c., similar to fraction D_{11}) was removed. The remainder (D_4, 1·72 g.) was chromatographed on alumina as described above. Table IX gives the characteristics of the fractions.

TABLE IX.—CHROMATOGRAPHIC ANALYSIS OF FRACTION D_4

Fraction.	Eluted with	Weight (g.).	Iod Val.	Comments
D_{41} ..	30 ml. pet. ether ..	0·25	63	Colourless solution.
D_{42} ..	15 ml. ,, ..	0·31	130	Yellow solution.
D_{43} ..	10 ml. ,, ..	0·02	..	
D_{44} ..	25 ml. ,, ..	0·11	..	Red band on column; orange solution.
D_{45} ..	20 ml. ,, ..	0·07	..	
D_{46} ..	40 ml. ,, ..	0·04	86	Light yellow solution: rejected.
D_{47} ..	20 ml. ,, ..	0·02		
D_{48} ..	50 ml. ,, ..	0·06	86	Diffuse orange band on column; yellow solution.
D_{49} ..	50 ml. ,, ..	0·03		
D_{410} ..	40 ml. ,, ..	0·02	80	Light yellow solution: rejected.
D_{411} ..	25 ml. ,, ..	0·00		
D_{412} ..	25 ml. acetone ..	0·01	..	Light yellow solution; rejected.
D_{413} ..	10 ml. ,, ..	0·55	79	Brown band on column.
D_{414} ..	50 ml. , ..	0·02	70	Rejected.
D_{415} ..	50 ml. ,, ..	0·09	7	Light yellow.
D_{416} ..	Desorbed with acetone and benzene	0·10	32	

From the above table it can be seen that this fraction is complex and contains at least five components. Fractions D_{41} and D_{42}, which were only slightly adsorbed from petrol by alumina, probably consisted largely of hydrocarbons. The low iodine values indicate, however, that the bulk was neither squalene (iod. val. 371) nor hepene (iod. val. 329). Fraction D_{42} was combined with fraction D_{43} and crystallized from acetone at —40°c. A trace of white crystals was removed, and the remainder dissolved in acetone was saturated with dry HCl gas at 0°c. The solution rapidly darkened in colour, but no crystals separated overnight or after subsequent evaporation to small bulk and cooling.

DISCUSSION

The Fatty Acids of Low Molecular Weight

Hilditch and Pedelty(7) obtained by ester-fractionation evidence for the presence of *ca* 0·1 per cent. of lauric acid in pig depot fat. Comparison of the estimates of the amount of low molecular weight fatty acids in the diets of pigs similar to those used by Hilditch and Pedelty (*cf.* (8)) and by the present investigators (*cf.* (1)) shows that our pigs, being buttermilk fed, were, as compared with the pigs of the latter authors, fed more of these acids. Correspondingly small amounts of capric acid (0·2 per cent.) and lauric acid (0·2 per cent.) have been identified as constitutents of the depot fat.

Elsewhere(1) we have discussed the fact that in the pig, as in the rat, the ratio of dietary acid to deposited acid is much greater for capric and for lauric acids than for the usual major component acids of the depot fat. The present work confirms, however, that small amounts of these low molecular weight saturated acids are assimilated from the diet and deposited unchanged.

The ester-fractionation data of Table II indicates that both C_{10} and C_{12} fractions contained small amounts of unsaturated acids. Crystallization from acetone of the acid recovered from the C_{10} fractions gave a soluble portion (iod. val. 57, neut. equiv. 173·0) consistent with the presence of decenoic acid in this fraction. The nature of the unsaturated material accompanying the C_{12} fraction is, however, more obscure. Although pure C_{10} fractions were obtained without difficulty, fractionation both of the ethyl esters and of the methyl esters failed to give a substantially pure C_{12} fraction. Crystallization from acetone of the acids recovered from fractions intermediate in molecular weight between C_{10} and C_{12} gave, however, good yields of almost pure lauric acid. The possibility exists, therefore, that these fractions were contaminated with small amounts of a less volatile acid of lower molecular weight, possibly a keto-acid.

It is desirable at this point to make a comment concerning interpretation of results obtained by ester fractionation when only small amounts (10–50 g.) of fat are available for analysis. When the acids are divided into " solids " and " liquids " by crystallization of lead soaps from alcohol or by crystallization of the acids or esters from acetone, the " liquids " contain some myristic acid and any lower molecular weight fatty acids, and these, when present in small amount, appear on distillation of the corresponding methyl esters, in the first liquid fraction, contaminated with methyl palmitate and methyl hexadecenoate. Now, it is not desirable to collect an initial fraction of more than 1-2 g., in case of further contamination with C_{18} esters ; a determination of the equivalent of the saturated portion is necessary, however, for evaluation of the composition. The oxidation method of Armstrong and Hilditch(9) may be used for this purpose(10), but it is accurate only when larger amounts (5–10 g.) of material are available for oxidation. It is usual, therefore, to make the assumption that the saturated and unsaturated esters have the same equivalent (*cf.* (10), p. 400), but in practice this assumption is probably often unjustified, especially when an efficient fractionating column is used. In this laboratory for pig depot fats, calculations making the above assumption have given tetradecenoic acid contents of *ca* 1 per cent. Table X gives the results of refractionation of esters from the bulked initial fractions of a number of typical analyses.

TABLE X.—REFRACTIONATION OF METHYL ESTERS FROM COMBINED INITIAL LIQUID FRACTIONS OF PIG BACK FATS

Fraction No.	Weight (g.).	b.p. (°c.).	Sap. Equiv.	Iod. Val.	Saturated Esters (g.).			Unsaturated Esters (g.).		
					C_{12}.	C_{14}.	C_{16}.	C_{14}	C_{16}.	C_{18}.
1 ..	1·626	–90	215·7	8·5	1·495	..	..	0·131	..	..
2 ..	2·054	90–95	238·1	7·2	0·248	1·666	..	0·140	..	..
3 ..	2·093	95	240·4	6·6	0·102	1·860	..	0·131	..	..
4 ..	2·332	95–110	243·1	8·5	..	2·047	0·095	0·167	0·023	..
5 ..	3·478	110	263·3	59·0	..	0·284	1·031	0·324	1·850	..
6 ..	3·195	..	270·4	51·8	..	..	1·436	..	1·579	0·180
Totals	14·789	..	..	..	1·845	5·857	2·562	0·893	3·452	0·180
Percentage esters			..	..	12·5	39·7	17·3	6·0	23·3	1·2

The incorrectness of the assumption that, in fractions intermediate between C_{14} and C_{16}, the saturated and the unsaturated components have the same mean equivalent is evident from fraction 5, which, although mainly C_{16}, appears on the above basis to contain, as compared with the immediately preceding almost pure C_{14} fraction, a greater proportion of methyl tetradecenoate. Even calculating the composition of this fraction as shown in the table, not making allowance for any unsaturated acids of molecular weight less than 240, the refractionation data indicates no more than 6 per cent. of methyl tetradecenoate in the combined esters, as compared with 20 per cent. calculated from the original saponification equivalent (247·4) and iodine value (29·3), assuming that 247·4 also represents the saponification equivalent of the unsaturated esters present.

In general, therefore, unless the amount of fat used for analysis is large enough for isolation of an almost pure C_{14} fraction with only small intermediate fractions, it seems peferable not to record tetra- and hexa-decenoic acids separately. Similar considerations apply to calculations of the composition of fractions containing decenoic and dodecenoic acids; in general, however, the iodine values of C_{10}, C_{12}, and C_{14} fractions are not very different and the error involved is smaller.

The C_{20} Fractions

Fraction S_{5611}, Table VI (neut. equiv. 340·3) after recrystallization from acetone and from petroleum ether melted at 73·5–74°c. Arachidic acid (neut. equiv. 312) melts at 75·4°c.; behenic acid (neut. equiv. 340) melts at 80°c., and its melting-point is depressed to 74°c. on admixture with 25 per cent. of lignoceric acid (neut. equiv. 368) or of arachidic acid. Without examination by x-ray diffraction, it can only be said that a considerable portion (probably 50 per cent.) of the acids of higher molecular weight than stearic acid were homologues higher than arachidic acid. From the data of the tables it may be estimated that the total quantity of arachidic acid and its higher homologues in the original fat was approximately 0·1 per cent. The source of these acids is undetermined; milk fat is recorded as containing arachidic, behenic, lignoceric, and cerotic acids(12); the fat of forage grasses (to which our pigs had some access) contains a similar mixture(13).

The Unsaponifiable Matter

The approximate composition of the various fractions of the unsaponifiable matter are given in Table XI.

TABLE XI. APPROXIMATE COMPOSITION OF UNSAPONIFIABLE MATTER

Fraction.	$D_1 + D_{21}$.	$D_{22} - D_{28}$	D_2.	Total	Percentage Unsaponifiable	Percentage Total Fat.
Saturated hydrocarbons	0·25	0·04	0·13	0·42	11·3	0·02
Other hydrocarbons .	..	..	0·58	0·58	15·2	0·03
Cholesterol .. .	0·02	0·80	0·61	1·43	37·5	0·07
Unidentified material	0·12	0·13	1·13	1·38	36·0	0·07
Total ..	0·39	0·97	2·45	3·81	100·0	0·19

The isolation of cholesterol as the largest single component needs little comment in view of the widespread occurrence of this compound in animal tissues. It is interesting, however, that in a preliminary examination of the unsaponifiable matter an attempt was made to isolate cholesterol from the crude (hot methyl alcohol soluble, cold methyl alcohol insoluble) fraction by recrystallization. The most pure fraction melted at 135–8° c. After removal of contaminating saturated hydrocarbon by chromatographic adsorption, however (*cf.* Table VII), no difficulty was found in obtaining good yields of almost pure cholesterol, melting-point 147° c.

In regard to the possible presence of other sterols, it may be noted that the crude sterol fraction D_2 was examined spectroscopically by Mr. W. S. Metcalf of this laboratory. Ergosterol and spectroscopically similar substances such as 7-dehydrocholesterol were not present in amounts greater than 1 per cent. Windaus and Bock(14) have recorded that the crude sterol of pigskin contains 6 per cent. of 7-dehydrocholesterol.

Many saturated hydrocarbons are known to occur in plant and animal fats. Thus nonacosane has been identified in the unsaponifiable matter from cacao fat(15) and from cabbage leaf(16). Stranger *et. al.*(17) detected a saturated hydrocarbon as 20 per cent. of the cholesterol-free unsaponifiable matter from human liver fat, and Ruzicka *et al.*(18) found a saturated hydrocarbon, melting-point 51°, in the unsaponifiable matter of hog spleen. The main fraction of saturated hydrocarbon isolated in the present work from pig depot fat unsaponifiable matter approximated in analytical characteristics to hexacosane ($C_{26}H_{54}$). The melting-point was not sharp, however, and it is fairly certain that the fraction was a mixture further characterizable only by x-ray examination.

The basis for inclusion of "other hydrocarbons" in Table XI is the very weak adsorption of fractions D_{41}–D_{43} (Table IX) on alumina. Their nature is not established; unsaturation, though high, (D_{42}, iodine value 130) did not approximate to that of squalene (iodine value 371) or hepene (iodine value 329(17)). Neither of the latter compounds were identified as hydrochlorides, though it may be noted that Fitelson(19) showed the presence in lard of squalene to the extent of 3 mg./100 g. On the other hand, Dimter(20, 21) states that hepene and squalene are absent from human and other mammalian body fats and serum fats.

Concerning the unidentified material, it can be said that at least three pigments were present as well as several colourless or slightly coloured materials. The fractions most strongly adsorbed on alumina (D_{415} and D_{416}) had low iodine values and possibly contained high molecular weight ketones or alcohols.

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REFERENCES

(1) SHORLAND, F. B., and DE LA MARE, P. B. D. (1945): *J. Ag. Sci.*, *35*, 33.
(2) DE LA MARE, P. B. D., and SHORLAND, F. B.: *Biochem, J.* (In press.)
(3) SHORLAND, F. B.; HANSEN, R.; and HOGAN, K. J. (1944): *Emp. J. Exp. Ag.*, *12*, 103.
(4) LONGENECKER, H. E. (1937): *J. Soc. Chem. Ind.*, *56*, 199T.
(5) LAPWORTH, A., and MOTTRAM, E. N. (1925): *J. Chem. Soc.*, *127*, 1628.
(6) GREEN, T. G.; HILDITCH, T. P.; and STAINSBY, W. J. (1936): *J. Chem. Soc.*, p. 1750.
(7) HILDITCH, T. P., and PEDELTY, W. H. (1940): *Biochem. J.*, *34*, 40.
(8) HILDITCH, T. P.; LEA, C. H.; and PEDELTY, W. H. (1939): *Biochem. J.*, *33*, 493.
(9) ARMSTRONG. E. F., and HILDITCH T. P. (1925): *J. Soc. Chem. Ind.*, *44*, 43T.
(10) HILDITCH, T. P. (1939): "The Chemical Composition of Natural Fats." Chapman and Hall, London.
(11) SCHUETTE, H. A., and VOGEL, H. A. (1940): *Oil & Soap*, *17*, 155.
(12) HELZ, G. E., and BOSWORTH, A. W. (1936): *J. Biol. Chem.*, *116*, 203.
(13) SMITH, J. A. B., and CHIBNALL, A. C. (1932): *Biochem. J.*, *26*, 218.
(14) WINDANS, A., and BOCK, F. (1937): *Zeit. Physiol. Chem.*, *245*, 168.
(15) RUPPOL, E. (1943): *J. Pharm. Belg.*, *2*, 26.
(16) CHANNON, H. J., and CHIBNALL, A. C. (1929): *Biochem. J.*, *23*, 168, 176.
(17) STANGER, D. W.; STEINER, P. E.; and BOLYARD, M. N. (1944): *J. Am. Chem. Soc.*, *66*. 1621.
(18) RUZICKA, L. (1944): *Chem. Abs.*, *38*, 3334.
(19) FITELSON, J. (1943): *J. Assoc. Off. Ag. Chemist*, *26*, 499, 506.
(20) DIMTER, A. (1941): *Zeit. Physiol. Chem.*, *270*. 247; *271*, 293.
(21) ——— (1942): *Ibid.*, *272* 189.

ALKALOIDS OF THE LEGUMINOSAE

PART XVI—ALKALOIDS OF *GENISTA AETHNENSIS* DC.

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Summary

The only alkaloid of seeds of this species is cytisine. Tops of one plant gave a steam-volatile fraction (0·6 per cent.) containing some sparteine, but mainly retamine. Another apparently identical plant gave no sparteine and only a trace of retamine in the volatile fraction. Samples from both plants gave by the ordinary extraction method 0·3–0·7 per cent. of base, consisting of retamine, with a small amount of cytisine, and a trace of other cytisine-like base.

Genista aethnensis DC. was previously reported to contain cytisine in seeds(1), and it is here confirmed that the only base of seeds (0·6 per cent.) is cytisine. The presence of much steam-volatile base taken to be sparteine, was reported in tops(1). The plant formerly used was obtained from Spreydon Domain, Christchurch. Further examination of it showed that the steam-volatile fraction (about 0·5 per cent.) contained some sparteine, but was

mainly the allied base, retamine. Two large samples from an apparently identical plant from the Botanic Gardens, Christchurch, gave very little steam-volatile base, which was retamine, with no sparteine. The greater part of the "sparteine" reported in this species by Jaretzky and Axer(2) is probably retamine, as these workers used the steam-distillation method.

The fractions of alkaloid obtained from both plants by the ordinary extraction method with chloroform (0·3–0·7 per cent.) were identical. The "cytisine-like" material previously reported(1) is cytisine, constituting about a third of the total alkaloid. A trace of cytisine-like base in the mother liquors could not be identified, and gave no suitable derivatives. The water-insoluble fraction previously reported to have a m.p. 151°(1) constitutes more than half of the total base. Large quantities of this fraction have now been isolated, purified, and found to be a base, $C_{15}H_{26}ON_2$, m.p. 162°, $[\alpha]_D + 41\cdot45°$ (alcohol), with a solubility 1·8 g. in 100 ml. of alcohol at 17°. These values agree closely with those reported for retamine. Other analytical data, properties, and reactions were in agreement with those of retamine, and the presence of an alcoholic group was shown by acetylation, the acetyl derivative being a base, m.p. about 10°

Retamine, a hydroxy sparteine $C_{15}H_{26}ON_2$, was isolated from tops of *Genista spaerocarpa* Lam. (*Retama spaerocarpa* Boiss.) by Battandier and Malosse(3), and later by Wunschendorff and Valier(4, 5). It occurs in tops of this plant to about 0·4–0·5 per cent., with no other reported alkaloid. No known source of the base is available in this country. Another base of similar constants is that reported by Orechov(6), m.p. 162–4°, $[\alpha]_D + 54\cdot4°$ (methanol), from *Anabasis aphylla* (Chenopodiaceæ), in which bases closely related to lupanine were found.

The slight volatility of retamine in steam has not previously been reported. The dihydrochloride was prepared, m.p. 298°, the monomethiodide, m.p. 217°, and the dipicrate dihydrate, m.p. 155–165°. The gold chloride as precipitated had a m.p. 201°, lowered to 188° on recrystallization. The microchemical slide reactions showed some similarity to those of sparteine and monspessulanine.

EXPERIMENTAL

Isolation of Bases: Identification of Cytisine

14·3 g. of seeds gave 84 mg. of crude alkaloid, $[\alpha]_D - 104$ (alcohol), entirely soluble in a little water or alcohol. It gave the microchemical reactions of cytisine; and the picrate, m.p. 274° (dec.), obtained in a high yield showed no depression on admixture with cytisine picrate of the same m.p.

313 g. of **stl** (February), (a mixed sample mainly from Christchurch Botanic Gardens) gave 2·02 g. of crude base which was mostly solid and insoluble in water. Excess water was added and the suspension steam-distilled. The distillate was acidified and dried, forming 200 mg. of deliquescent hydrochloride. The base from this formed 99 mg. of semi-solid material, $[\alpha]_D + 20°$ (alcohol), having the odour of sparteine. The presence of sparteine in this base was established by the slide reactions with potassium cadmium iodide, gold chloride, and the bromosalts, the precipitates being much less soluble than those of retamine. Recrystallization of the base gave retamine. The residue from the steam distillation was concentrated to 20 ml., and the crystalline precipitate, 0·73 g., m.p. 160–1°, was filtered off. Recrystallization from hot alcohol gave 0·66 g. of colourless needles, m.p. 162°. The aqueous fraction was made alkaline and base was recovered by extraction with chloroform, as a semi-crystalline varnish weighing 0·60 g., $[\alpha]_D - 48°$ (c = 3·03 in alcohol), and giving the van der Moer reaction.

Extraction with a little water left a further 110 mg. of impure retamine. The aqueous solution gave 320 mg. of base, $[\alpha]_D$ — 73°, and with benzenesulphonylchloride and alkali gave 110 mg. of benzenesulphonylcytisine, m.p. 256°. The mother-liquor again extracted with chloroform gave 130 mg. of base, $[\alpha]_D$ — 74° (c = 1·32 in alcohol). This base gave the van der Moer reaction, but no crystalline derivatives could be prepared from it.

43 g. of **stl** (October), (Spreydon Domain) were extracted with 5 per cent. hydrochloric acid, made alkaline, and steam-distilled. The distillate, containing oily drops of the odour of sparteine, was caught in very dilute hydrochloric acid and dried, giving 281 mg. of deliquescent hydrochloride, $[\alpha]_D$ + 18° (water). Solutions gave strong reactions of sparteine, not given by retamine in dilute solution. The solution was made alkaline and extracted with chloroform, giving 135 mg. of base, a solid, and a dark liquid having the odour of sparteine and fuming with acid. The picrate was prepared from aqueous solution forming about 200 mg. of rods, m.p. 153 6°. On recrystallization, various fractions melted at 147 158° and did not show further depression on admixture with retamine picrate, m.p. 158°. The mother-liquor from the steam distillation gave on extraction with chloroform 281 mg. of base containing retamine and cytisine.

319 g. of **stl** (September), (Christchurch Botanic Gardens) were extracted, clarified with lead acetate, made just alkaline, and steam-distilled. The distillate was acidified with very dilute hydrochloric acid and dried when a slight residue remained. This gave feeble microchemical reactions in concentrated solution, gave an iodocadmium salt like that of sparteine or retamine, and was composed largely of ammonium chloride. The mother-liquor from the steam distillation was extracted with chloroform, giving 0·90 g. of discoloured base. 653 g. of the same sample, extracted in the normal way, gave 1·47 g. of discoloured crystalline base. This was combined with the 0·90 g. lot. The whole was ground with water, leaving 0·93 g. of almost colourless crystals. Recrystallization of this fraction from hot alcohol gave 550 mg. of colourless rods, m.p. 162°, and from the mother-liquors of the recrystallization further retamine was isolated by petroleum ether extraction. The original water-soluble fraction was extracted with chloroform, giving 1·18 g. of crystalline base, $[\alpha]_D$ — 70° (alcohol), mostly soluble in a little water. The aqueous solution was shaken with benzenesulphonylchloride and alkali, the suspension made slightly acid to dissolve traces of any water-insoluble base, and 0·98 g. of benzenesulphonylcytisine, m.p. 260°, was obtained. The mother-liquor was extracted with chloroform to give 420 mg. of partly crystalline base, $[\alpha]_D$ — 40°. The aqueous solution of this base was made alkaline and extracted with petroleum ether, giving 180 mg. of crystalline base, $[\alpha]_D$ + 20°, mainly retamine. The solution was then extracted with chloroform, giving 160 mg. of varnish-like base, $[\alpha]_D$ — 124°, soluble in water and giving the van der Moer reaction. The picrate from alcohol was amorphous and could not be crystallized.

Identification of the Retamine Fraction

Retamine Base.—The base, m.p. 162°, was almost insoluble in cold water very slightly soluble in hot water, and sparingly in alcohol. It was slightly volatile in steam from aqueous or slightly alkaline solution, much more volatile in the presence of sparteine. Retamine has a m.p. 162°(3), 168°(4), and similar solubilities. Analysis gave—

—	Found.	Calculated for $C_{15}H_{26}ON_2$.
C	72·10	72·00
H	10·62	10·40
N	11·0	11·20

Methoxy and CH_3(N) determinations were negative; molecular weight (Rast) = 228, calculated 250.

The base had $[\alpha]_D + 41°$ ($c = 0{\cdot}929$ in alcohol), $[\alpha]_D + 46°$ ($c = 0{\cdot}538$ in alcohol), recorded $[\alpha]_D + 43{\cdot}25°$ ($c = 2{\cdot}0$ in alcohol), $[\alpha]_D + 43{\cdot}18°$ ($c = 1{\cdot}0$ in alcohol)(3). 1·85 g. of base formed a saturated solution in 100 ml. of alcohol at 17°, recorded 1·964 g. at 17°(3). The base was soluble in petroleum ether, separating from it in needles as reported for retamine(3). The aqueous solution gave no van der Moer reaction, but formed a brown precipitate with ferric chloride. On refluxing with acetic anhydride, an acetyl derivative was formed. This was obtained as a thick syrup, m.p. about 10°, and had basic properties. Treatment of the base with sulphur dioxide for two days, with zinc dust and alkali, or by electro-chemical reduction gave no change.

Retamine Dihydrochloride. The base was dissolved in excess dilute hydrochloric acid and dried. Recrystallization from alcohol-acetone formed plates, m.p. 287°. The salt was dried at 100° for two days, then having a m.p. 298°. It gave Cl = 22·6, 22·3 (theory for $C_{15}H_{26}ON_2,2HCl$ Cl 22·0). Retamine is known to form *di*-salts(3).

Retamine *Methiodide.* The base in acetone was refluxed with excess methyl iodide, forming needles, m.p. 205°. Recrystallization from hot acetone formed rods, m.p. 217°, 216°. Analysis gave

—	Found	Calculated for $C_{15}H_{26}ON_2,CH_3I$.
I	32·7, 32·8	32·5
CH_3(N)	3·6, 3·5	3·8
N	7·1	7·14

Retamine Dipicrate Dihydrate. A slightly acid solution of the base with excess aqueous picric acid formed an amorphous precipitate, giving needle clusters, m.p. 213°, on warming. Recrystallization from water gave rods, m.p. 155°, and further from alcohol rods, m.p. 165–7°. Another preparation from warm aqueous solution gave rods, m.p. 165°, recrystallized from alcohol as rods, m.p. 156°. Melting-points were not sharp. There was no water loss at 100°. Analysis gave

—	Found.	Calculated for $C_{15}H_{26}ON_2,2C_6H_3O_7N_3,2H_2O$
Picric acid†	62·4	61·5
N	15·0	15·06

† As nitron picrate

Retamine Aurichloride.—An acid solution of the base with excess gold chloride formed prisms, appreciably soluble in water, m.p. 201–3° (dec.). Recrystallization from very dilute hydrochloric acid (with separation of some gold) gave rods, m.p. 193°, and these further recrystallized from alcohol formed rods, m.p. 189°. The alcohol-recrystallized salt gave Au = 37·8; theory for $C_{15}H_{26}ON_2,HAuCl_4$ is 33·4.

Microchemical Slide Reactions of Retamine

Slightly acid solutions gave with potassium bismuth iodide an amorphous precipitate and with potassium mercuric iodide irregular needle clusters and fern-like forms. Potassium cadmium iodide gave crystals similar to those

given by sparteine or monspessulanine, curved blades with transverse outgrowths. Potassium tri-iodide formed only an oil, gold bromide characteristic blades or rod clusters, and gold chloride only in concentrated solutions rods and prisms, isolated and clustered, rather like those with sparteine. The precipitate with picric acid was amorphous. Mercuric chloride gave a slight oily precipitate giving a few small crystals in concentrated solution. Potassium mercuric bromide formed in concentrated solution a few spheroids, and the other bromo salts gave no precipitates. Potassium ferricyanide gave no precipitate even in very concentrated solution. This fact, and the higher solubility of retamine precipitates, serve to distinguish this base from sparteine.

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REFERENCES

(1) WHITE, E. P. (1944): *N.Z. J. Sci. & Tech.*, *25 (Sec. B)*, 149, 150.
(2) JARETZKY, R., and AXER, B. (1934): *Arch. Pharm.*, *272*, 152.
(3) BATTANDIER, J., and MALOSSE, T. (1897): *Comp. Rend.*, *125*, 360 and 450.
(4) WUNSCHENDORFF, M. H. and VALIER, P. (1933): *Bull. Sci. Pharmacol.*, *40*, 601
(1934): *Chem. Abs.*, *28*, 858.
(5) VALIER, P. (1933): *Bull. Sci. Pharmacol.*, *40*, 520.
(6) ORECHOV, A. P. (1937): *J. Gen. Chem. (U.S.S.R.)*, *7*, 2048.
(1938): *Brit. Chem. Abs.*, *A*, *ii*, 74.

PART XVII.—ALKALOIDS OF *VIRGILIA CAPENSIS* LAM.

Summary

Tops of *Virgilia capensis* contain 0·5–1·1 per cent. of alkaloid consisting of several bases.

Virgiline, $C_{16}H_{26}O_2N_2$, m.p. 248°, is a new monoacid base, apparently related to sparteine, but containing an additional C-methyl group, inert keto and alcoholic — OH group. A hydrochloride monohydrate, picrate hexahydrate, methiodide, and O — acetyl derivative were prepared. It constitutes a third of the total alkaloid.

Virgilidine, $C_{10}H_{19}ON$, is a semi-crystalline base, b.p. 90° at ca. 0·01 mm., and is a *d*-isomer of lupinine, which it resembles closely. A methiodide and picrate were prepared. It constitutes a tenth of the total base.

About a tenth of the total base was obtained as a hygroscopic syrup, forming a methiodide and gold chloride of a base $C_{15}H_{24}ON_2$. This and other properties were in agreement with a mixture of *dl*-lupanine with some of the *d*-form.

The remainder of the base formed ill-defined hygroscopic material from which nothing crystalline could be obtained.

IN the *Sophoreae* the genus *Sophora* has been extensively investigated for alkaloids, which have been found in about nineteen species. Detailed studies have shown many alkaloids allied to cytisine, sparteine, and matrine in this genus. Alkaloids have also been found in the genera *Ammodendron*, (*d*-sparteine and ammodendrine, a *dl*-N-acetyl piperidylpiperidine with one double bond) *Ammothamnus*, *Ormosia* (ormosine and ormosinine), and has been detected in *Bowdichia*.

Virgilia is a monotypic genus. *V. capensis* Lam. was previously reported(1) to contain in its tops much lupanine-like alkaloid. Subsequent investigation of another plant previously described as *Sesbania tripetii*(1) showed the alkaloid to be the same as that of *Virgilia*, and botanical study then showed the supposed *Sesbania* to be a variety of *V. capensis*. Reference to *Sesbania*(1) should be deleted.

TABLE I.—COMPARISON OF THE KNOWN $C_{10}H_{19}ON$ ISOMERS

Alkaloid.	Base	Hydrochloride.	Methiodide.	Picrate.
Virgilidine	Semi-crystalline, b.p. (0·01 mm.) 87–94°. $[\alpha]_D$ + 12° (alcohol). n_D^{17} = 1·5128. Soluble in petrol-ether, sparingly soluble in water, less in hot. Steam-volatile	Syrup	M.p. 256–9° ..	M.p. 203°, from water-acetone.
l-Lupinine	Prisms, m.p. 68–9°(5), 68–9°(6), 70–1°(7). $[\alpha]_D$ — 20·91° (alcohol)(6). Soluble in petrol-ether(7), soluble in water, less in hot(7). Steam-volatile (own observation)	Crystalline, m.p. 207–9°(6), 212–3°(8), 211·5–212·5 (5), 210 (own observation)	M.p. 295–6°(6) 305–6 (dec.)(7)	M.p. 196–7°(6), from water-acetone.
dl-Lupinine (synthetic)(9)	B.p. (1 mm.) 107°, m.p. 59°	..	M.p. 303° (dec.)	..
d-Lupinine (synthetic)(10)..	M.p. 68°. $[\alpha]_D$ + 19·9° ..	..	..	..
Isolupinine	M.p. 76–8°(11), 77–9°(6). $[\alpha]_D$— 38·17°	..	..	..
dl-Iso-lupinine (synthetic)(10)	B.p. 122° (1 mm.), m.p. 81° ..	..	..	..
Tetralupine*(6)	Crystals, m.p. 81–3°. $[\alpha]_D$ + 4·63° (alcohol). n_D^{26} = 1·5128. Soluble in water, insoluble in petrol-ether	..	..	..

*Tetralupine gold chloride is very soluble in water, that of the other bases is sparingly soluble

Preliminary estimations on this species showed values (in terms of lupanine, by titration) **stl** (February) 1·2, 1·4, 1·1, 0·65, 0·35, **st** (February) 0·46, 1·15, 0·94, **l** (February) 0·22, 0·88, 0·62, **fls** 0·69. Sufficient seeds for chemical study could not be obtained. In the tops four bases were recognized, and at least one of these is a new base.

Virgiline, $C_{16}H_{26}O_2N_2$, m.p. 247–8°, $[\alpha]_D$ — 46° (alcohol), was separated by its slight solubility in acetone and water. It formed a mono-hydrochloride monohydrate, m.p. 262°, a monomethiodide, m.p. 176°, a monopicrate hexahydrate fairly soluble in water, m.p. 188–9°, and a mono-O-acetyl derivative, m.p. 174°. It contains only tertiary nitrogen, and is probably allied to sparteine, containing in addition a C-methyl group, an inert keto group, and an alcoholic — OH group. Orechov(2) obtained a base, $C_{16}H_{24-26}O_2N_2$, m.p. 137°, from *Anabasis aphylla*, and dilupine, $C_{16}H_{26}O_2N_2$, of *Lupinus barbiger*(3) is an amine-oxide of a methyl lupanine.

A second base, Virgilidine, $C_{10}H_{19}ON$, was separated from the remaining bases by fractional distillation, forming a low b.p. (87–94° at 0·01 mm.) fraction. It forms a semi-crystalline syrup, $[\alpha]_D$ + 12° (alcohol), n_D^{17} = 1·5128, volatile in steam. The hydrochloride was a syrupy material, the picrate had a m.p. 203°, and the methiodide a m.p. 256 9 . Comparison is made with lupinine and other known isomers of $C_{10}H_{19}ON$ in Table I. Virgilidine may be *d*-lupinine, but there is not sufficient evidence for comparison. The *d*-isomer has been obtained by resolution of synthetic *dl*-lupinine. In microchemical reactions there was similarity to lupinine obtained from *Lupinus luteus*, and it resembled this base further in containing only tertiary nitrogen and in being capable of acetylation.

A higher b.p. fraction (138–145° at 0·01 mm.) was composed of a further syrupy base retaining traces of moisture and solvents. It had $[\alpha]_D$ + 25° (alcohol), formed a varnish-like hydrochloride, a methiodide $C_{15}H_{24}ON_2$, CH_3I, m.p. 253°, and an aurichloride $C_{15}H_{24}ON_2$,$HAuCl_4$, m.p. 193°. It is probably a mixture of *dl*-lupanine with some of the *d*-form, similar to the bases of *Podalyria* species(4).

The remaining base (about a third of the total) was varnish-like and hygroscopic, and gave no crystalline derivatives. It could not be identified, and was not lupanine.

EXPERIMENTAL

Extraction and Separation of Bases

Continuous extraction methods were used for all material. The crude base from some earlier small-scale investigations on samples from different sources was a thick discoloured syrup, $[\alpha]_D$ — 10° to — 25° (alcohol). None of these bases gave any colour with ferric chloride, all were sparingly soluble in water, and only extractable in part by hot hexane. No perchlorate could be obtained from perchloric acid and sodium acetate solutions, and there was no appreciable steam-volatile fraction.

200 g. of **stlfl** (February, 1943, from Christchurch Botanic Gardens) gave 2·23 g. of crude alkaloid, a syrup $[\alpha]_D$ — 12° (alcohol). 1·518 kg. of **stlfl** from the same tree (February, 1944) was extracted in small amounts at a time, and 10·2 g. of crude dark base obtained after drying from methanol. This was combined with the 2·2 g. lot. The crude base gave no ferric chloride colour, was soluble in alcohol, but only sparingly in water and ether. The whole was ground with 20 ml. of acetone and allowed to stand overnight. The crystalline material remaining was washed with a little acetone. This fraction weighed 3·18 g., m.p. 242–4° (dec.), and was designated base " A."

The acetone solution on drying gave 8·30 g. of thick syrup, $[\alpha]_D$ + 13° (alcohol). A further 0·3 g. of base " A " was removed by acetone digestion. The residual base was soluble in alcohol and acetone, sparingly in ether, petrol-ether, and water, and gave no easy separation into its components.

It formed a small yield of methiodide, m.p. 215–230°, gave no perchlorate from sodium acetate and perchloric acid, and a low yield of amorphous picrate of m.p. 55°.

5·26 g. of this fraction was distilled at approximately 0·01 mm. in a small efficient fractionating column. Fraction I, b.p. 87–94°, $[\alpha]_D + 12°$ (c = 1·374 in alcohol), n_D^{17} = 1·5128, was a thick syrup weighing 0·88 g., designated base "B." Fraction II was a thick syrup, $[\alpha]_D + 14°$ (c = 1·26 in alcohol), n_D^{17} = 1·5075, weighing 120 mg. It was largely base "B," with which it agreed also in microchemical slide reactions and in the m.p. of the methiodide. It became semi-crystalline on standing. Fraction III, b.p. 138–145°, was semi-solid, $[\alpha]_D + 20°$ (c = 0·935 in alcohol), n_D^{17} = 1·5279, and weighed 0·79 g. The fractionation was stopped after this stage, as the distillate was semi-solid and would not flow. Fraction IV, 0·82 g., was recovered from the column, and was a dark syrupy material almost insoluble in petrol-ether and having a slight optical rotation. Fraction V, 2·35 g., was the residue in the flask. It was a dark syrup, $[\alpha]_D$ 2° (alcohol). From this about 80 mg. of base "A" were removed by acetone. It was almost insoluble in petrol-ether.

Fractions IV, V, and a petrol-ether insoluble part of fraction III were combined. Extraction with acetone left an appreciable amount of dark tarry non-basic material, and a further amount remained insoluble in dilute acid. The extract was made alkaline and extracted with chloroform, giving 1·3 g. of a dark varnish, $[\alpha]_D + 7°$ (c = 1·27 in alcohol). The hydrochloride was only a varnish. Picric acid from aqueous solution formed an amorphous precipitate which on drying became black and sticky. The base on refluxing with methyl iodide in acetone formed only a syrup, which could not be obtained crystalline.

510 g. of **stlfl** (August, 1944, from Wellington) gave similarly 3·60 g. of crude base, $[\alpha]_D - 8°$ (alcohol). Digestion with acetone left 0·38 g. of crystals, m.p. 228°, showing no further depression on admixture with base "A." The acetone solution gave 2·41 g. of syrupy base.

Characterization of Base "A": Virgiline

Virgiline Base. Crude base "A," m.p. 243°, was recrystallized from hot acetone containing some methanol in the form of colourless shining prisms, m.p. 247–248·5°, sintering from 244°, $[\alpha]_D - 46°$ (c = 1·251 in alcohol). Analysis gave

	Found	Calculated for $C_{16}H_{26}O_2N_2$
C	69·11, 69·2	69·08
H	9·07, 9·4	9·35
N	10·3, 10·2	10·07

Methoxy and CH_3(N) negative.

Virgiline base is sparingly soluble in acetone and water, readily in methyl and ethyl alcohol, very slightly in ether and petrol-ether. 87·8 mg. of base did not dissolve in 5 ml. of water; the solution on titration to methyl red required 3·12 ml. of 0·100 N-hydrochloric acid, equivalent = 281. The base was recovered unaltered after refluxing for four hours with alcoholic potash. It was also stable to the action of sulphite and acid, and is thus not an amine-oxide.

Virgiline Monohydrochloride Monohydrate.—The solution from the titration was dried, dissolved in alcohol, and precipitated with acetone, forming needles and thin rods, m.p. 260–1° (dec.). Analysis gave—

—	Found.	Calculated for $C_{16}H_{26}O_2N_2.HCl.H_2O$.
C	57·5	57·74
H	8·8	8·72
N	8·36, 8·28	8·42
Cl*	11·2, 11·4	10·7

* Microtitration to dichlorofluorescein.

Virgiline Monomethiodide.—The base in methanol was allowed to stand with methyl iodide, but only free base was recovered. The mixture was refluxed for six hours, dried, and acetone added, when colourless crystals formed, m.p. 176°, sintering from 173°. Recrystallization from acetone containing methanol gave small prisms, m.p. 173–4° (with vigorous decomposition). It is readily soluble in water. Analysis gave—

—	Found	Calculated for $C_{16}H_{26}O_2N_2CH_3I$
C..	45·7	45·71
H	6·5	6·9
N	6·86	6·66
CH_3(N)	3·2	3·6
I*	30·7, 30·1	30·2

* Argentimetric with eosin indicator.

Virgiline Monopicrate Hexahydrate.—A slightly acid solution of the base with excess aqueous picric acid gave an amorphous precipitate forming plates overnight. These were recrystallized from hot water as shining plates, m.p. 188–9°. Analysis gave—

—	Found.	Calculated for $C_{16}H_{26}O_2N_2,C_6H_3O_7N_3$, 6 H_2O.
N	11·3, 11·2	11·36
Picric acid* ..	38·1	37·2

* As nitron picrate.

Monoacetylvirgiline.—Virgiline base was refluxed for four hours with excess acetic anhydride. The solution was dried and extracted with water, when some dark material remained insoluble. The aqueous solution, which was alkaline, was extracted with chloroform. On evaporation of the solvent a discoloured solid remained. This was extracted with hot ether, when most of the coloured material remained. The recovered solid recrystallized from acetone-ether gave slightly discoloured prisms, several fractions of which melted at 174°. Further recrystallization gave colourless prisms, m.p. 173–4°, sintering from 170°. Analysis gave—

—	Found.	Calculated for $C_{16}H_{25}O_2N_2,COCH_3$.
N	8·73	8·75
CH_3CO*	12·5	13·4

* Kuhn-Roth, with 30 per cent. sulphuric acid.

Acetylvirgiline is a base soluble in most organic solvents except petrol-ether.

Microchemical Slide Reactions of Virgiline.—A comparatively concentrated solution in very dilute acid was used. Potassium bismuth iodide gave a heavy amorphous precipitate. Potassium mercuric iodide gave much amorphous precipitate rapidly changing to needle clusters similar to those with cytisine and this reagent. In neutral solution, plate-like rods formed. Potassium cadmium iodide gave no immediate precipitate, but soon formed characteristic prisms or thin pointed plates, not like those formed with most leguminous bases and this reagent. Picric acid formed only a slight oil, mercuric chloride a trace of oil, and potassium tri-iodide a red oil giving some large clusters of rods with outgrowths. Gold chloride formed a slight amorphous precipitate, gold bromide an amorphous precipitate soon crystallizing to long needles with tufts of fine needles along their length. Potassium mercuric and potassium cadmium bromides, platinum chloride, and potassium ferricyanide gave no precipitate.

Characterization of Base "B": Virgilidine

Virgilidine Base.—Fraction I, on standing a week, began to crystallize, but remained only semi-crystalline after a year. Attempted recrystallization gave only a syrupy form. The base had a coniine-like odour and was volatile in steam, having then a sweet fruity odour like lupinine. Analysis gave—

—	Found.	Calculated for $C_{10}H_{19}ON$
C	70·4, 70·7	71·00
H	11·2, 11·2	11·24
N	8·31, 8·28	8·28

Virgilidine was appreciably soluble in cold water, less in hot water, and soluble in most organic solvents, including petrol-ether. 125·4 mg. of base were dissolved in water (10 ml.) and titrated with 0·100 N-hydrochloric acid, requiring 6·72 ml. for neutralization to methyl red, and an extra 0·3 ml. to methyl orange, equivalent = 176–186, calculated 169. Virgilidine was stable to nitrite and dilute acetic acid. On refluxing with benzoyl chloride much decomposition took place, and benzoylated material was isolated in an impure state.

Virgilidine Hydrochloride.—The solution from the titration was dried, and clarified with norite. Only a varnish-like hydrochloride remained, and from alcohol-acetone this formed only a syrup.

Virgilidine Picrate.—The aqueous solution of the hydrochloride was made slightly acid, and excess picric acid added. An amorphous precipitate formed, m.p. 108–11°. It was dissolved in hot acetone and thrown out by addition of water as an amorphous precipitate soon giving fine needles in clusters, m.p. 203° (dec.). Analysis gave—

—	Found.	Calculated for $C_{10}H_{19}ON,C_6H_3O_7N_3$.
Picric acid*	57·9	57·5

* As nitron picrate.

Virgilidine Methiodide.—Virgilidine in acetone and methyl iodide deposited rod clusters rapidly. After standing a day the solution was dried, leaving discoloured crystals, m.p. 247–8°. These were dissolved in hot methanol, and precipitated as colourless rods by addition of acetone, m.p. 256–9°. Analysis gave—

—	Found.	Calculated for $C_{10}H_{19}ON,CH_3I$.
C	42·9	42·44
H	7·1	7·08
N	4·58, 4·51	4·50
I	40·9, 40·0	40·8
$CH_3(N)$	4·5	4·82

The methiodide from fraction II was obtained in high yield (95 mg.), and had a m.p. 248°, and showed no depression on admixture with virgilidine methiodide, m.p. 257°.

Microchemical Slide Reactions of Virgilidine.—A slightly acid solution gave several fairly insoluble precipitates. Potassium bismuth iodide gave an amorphous precipitate forming some prisms in clusters. Potassium mercuric iodide gave only an oil, potassium cadmium iodide an oil forming some rod clusters. Gold chloride formed a slight oil giving spheroids, needle and plate clusters: gold bromide gave an amorphous precipitate forming small spheroids, some composed of fine needles. Potassium tri-iodide formed only an oil; mercuric chloride, picric acid, platinum chloride, potassium mercuric and potassium cadmium bromides, little, if any, precipitate. Fraction II gave very similar reactions. There was considerable resemblance to the reactions of *l*-lupinine, the latter alkaloid forming some crystals with potassium mercuric iodide and potassium tri-iodide, while the other reactions were not particularly different from those of virgilidine.

Investigation of Fraction III

The Base.—Analysis of this fraction gave—

—	Found.	Calculated for $C_{15}H_{24}ON_2$.
C	70·4	72·58
H	10·1	9·67

The base was extracted with acetone, when an appreciable amount of sticky material insoluble in alcohol and acids remained. The solution was dried and extracted with hot petrol-ether. The slight dark residue was mixed with fraction IV. The purified base, 0·49 g., was a thick syrup, $[\alpha]_D + 25°$ (c = 1·032 in alcohol), $n_D^{17} = 1·5288$. It was soluble in petrol-ether and other organic solvents, moderately in water. Analysis gave C = 68·3, H = 9·6, N = 8·7, 8·7, indicating retention of moisture and solvent. 92·0 mg. of the base was not completely soluble in 10 ml. of water, and to methyl red indicator required 3·45 ml. of 0·100 N-hydrochloric acid, equivalent = 266, calculated for lupanine = 248. The hydrochloride was not crystalline.

Fraction III Methiodide.—The base in acetone and methyl iodide deposited crystals rapidly. After standing overnight the precipitate was recrystallized from acetone-methanol, forming small prisms, m.p. 253–4°, sintering from 246°. Analysis gave—

	Found	Calculated for $C_{15}H_{24}ON_2CH_3I$.
C	49·5	49·23
H	6·5	6·92
N	7·1	7·18
I	32·0, 31·9	32·5
$CH_3(N)$	3·5	3·8

The methiodide, mixed with that of virgilidine, melted from 225°.

Fraction III Picrate.—An aqueous slightly acid solution of the base with excess picric acid gave a slight amorphous precipitate going oily on warming. The precipitate was dissolved by addition of alcohol, but on evaporation of the alcohol gave only an oil. Alcoholic solutions gave no precipitate.

Fraction III Aurichloride.—The aqueous solution of the hydrochloride was acidified and excess gold chloride added. The amorphous oily precipitate slowly crystallized to small prisms, m.p. 185°. Recrystallization from dilute hydrochloric acid gave, with slight reduction to gold, prisms and spheroids, m.p. 192–4°, sintering from 170°. Analysis gave—

—	Found.	Calculated for $C_{15}H_{24}ON_2.HAuCl_4$.
C	30·0	30·61
H	4·1	4·25
N	4·6	4·76
Au	36·0	33·5

Microchemical Slide Reactions of Fraction III.—Most reagents formed sparingly soluble precipitates with dilute acid solutions of the base. Nearly all were amorphous or oily, only the gold bromide forming slowly some spheroids. No precipitates were obtained with mercuric chloride or the bromo salts, and only a slight amorphous precipitate with picric acid. These reactions were similar to those of lupanine.

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REFERENCES

(1) WHITE, E. P. (1943): *N.Z. J. Sci. & Tech.*, *25 (Sec. B)*, 95, 96
(2) ORECHOV, A. P. and MENSCHIKOV, G. (1932): *Ber.*, *65*, 234.
(3) COUCH, J. F. (1936): *J. Am. Chem. Soc.*, *58*, 1298.
(4) WHITE, E. P. (1944): *N.Z. J. Sci. & Tech.*, *25 (Sec. B)*, 138.
(5) ORECHOV, A. P. and MENSCHIKOV, G. (1931): *Ber.*, *64*, 266.
(6) COUCH, J. F. (1934): *J. Am. Chem. Soc.*, *56*, 2434.
(7) CLEMO, G. R., and RAPER, R. (1929). *J. Chem. Soc.*, 1927.
(8) HENRY, T. A. (1939): "The Plant Alkaloids," III Ed., London, p. 122.
(9) CLEMO, G. R.; MORGAN, W. McG.; and RAPER, R. (1937): *J. Chem. Soc.*, 965.
(10) ——— (1938): *Ibid.*, 1574.
(11) KREIG (1928): *Diss.*, Marburg, quoted by(6).

NOTE ON TYROGLYPHID MITE SPECIES ON CHEESE IN NEW ZEALAND*

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IN the course of an investigation into methods for the protection of cheese from mite attack under wartime storage conditions in New Zealand, a survey has been made of the mite species found in factory curing rooms and bulk cool stores in this country. The majority of factory curing rooms examined have been without temperature control and have generally been found to harbour mite infestations, particularly on reject cheese, which is often retained and left undisturbed for many months. The following species of Tyroglyphid mites have been recorded from factories :—

(1) *Tyrophagus longior* (Gerv.), which was referred to, under the generic name *Tyroglyphus*, by W. F. Findlay(1) as causing cheese-mite itch in New Zealand during the 1914–18 war. In 1940 a mite sample from cheese in this country forwarded by the Entomology Division to the Imperial Institute of Entomology was identified as "*Tyroglyphus dimidiatus* Herm. (= *longior* Gerv.)." The species is of world wide distribution and has undergone numerous changes in synonymy. Prior to the recent investigations it was the only mite species known to attack cheese in New Zealand.

(2) *Tyrolichus casei* (Ouds.), formerly *Tyroglyphus siro* L., known in Europe as the common cheese-mite, which has not previously been recorded in New Zealand.

In bulk cool stores, where export cheese may be held for some months generally at temperatures between 40°F. and 50°F., a different series of mite species is involved in infestations. Here the following Tyroglyphids have been recorded :—

(1) *Tyroglyphus farinae* (L.), the flour-mite, a common pest of cereals. This species may exist on the mould which is generally found in association with infestations in cool stores, although, in the laboratory, a colony has proved capable of establishment and development over a period of several months on the surface of fresh, unmoulded cheese.

(2) *Glycyphagus* (s. str.) *domesticus* (de Geer), a species regarded as secondary and probably living on mould.

(3) *Glycyphagus (Lepidoglyphus) destructor* (Schr.) Ouds., which has similar food habits to those of *G. domesticus*.

Only a few isolated specimens of *Tyrophagus longior* Gerv. have been observed on cheese in cool storage.

REFERENCE

(1) FINDLAY, W. F. (1921) : *N.Z. J. Health and Hosp.*, **4**, 57–60.

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